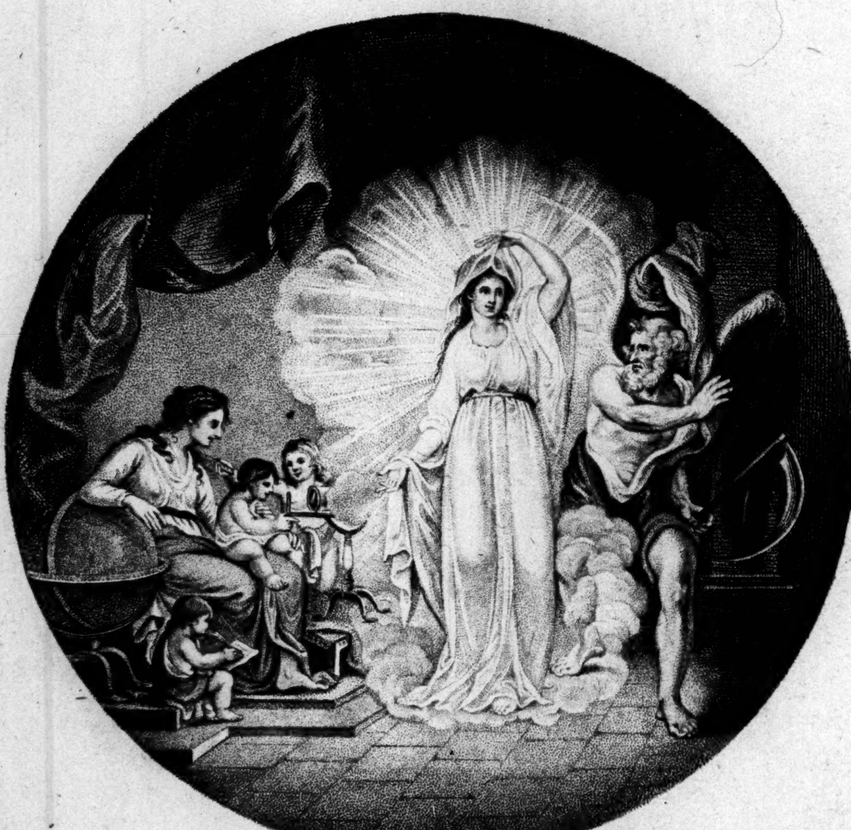

Truth discovering to Time,

Science instructing her Children, in Natural Philosophy.

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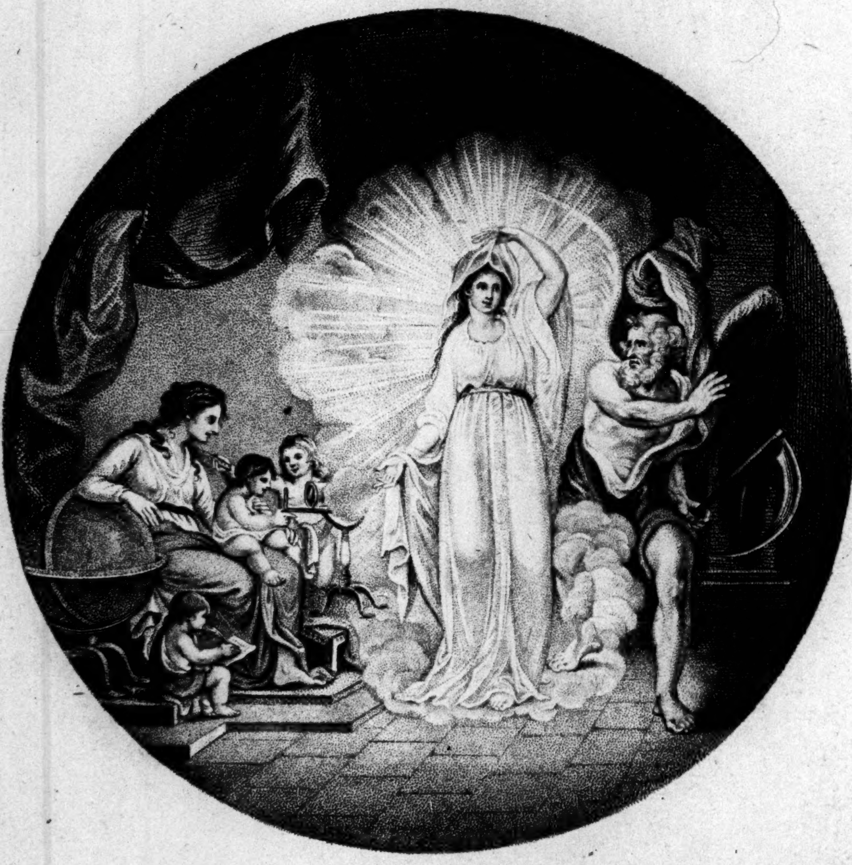

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LECTURES
ON
NATURAL AND EXPERIMENTAL PHILOSOPHY,

CONSIDERED IN IT'S PRESENT STATE OF
IMPROVEMENT.

DESCRIBING, IN A FAMILIAR AND EASY MANNER,
THE PRINCIPAL PHENOMENA OF NATURE;
AND SHEWING,
THAT THEY ALL CO-OPERATE IN DISPLAYING
THE
GOODNESS, WISDOM, AND POWER OF GOD.

BY GEORGE ADAMS,

Mathematical Instrument Maker to His Majesty, and Optician to His Royal Highness the Prince of Wales.

IN FIVE VOLUMES.
The Fifth Volume consisting of the Plates and Index.

VOL. I.

LONDON:
PRINTED BY R. HINDMARSH,
PRINTER TO HIS ROYAL HIGHNESS THE PRINCE OF WALES,
OLD-BAILEY.
SOLD by the AUTHOR, No. 60, FLEET-STREET.

1794.

TO HER

ROYAL HIGHNESS,

THE

PRINCESS ROYAL.

MADAM,

I BEG permiſſion to expreſs my grateful ſenſe of the honour Your Royal Highneſs has conferred on me, in permitting theſe Volumes to be inſcribed with Your Illuſtrious Name.

I moſt humbly preſent them to Your notice; and am enabled to do this with the greater confidence, from the nature of the ſubject, rather than from the manner of the execution. Every day's obſervation has pointed out the boundleſs wiſdom in the one, and the partial knowledge in the other.

Theſe Lectures are intended as a diſplay of the divine goodneſs, wiſdom, power, and order, manifeſted in the works of creation. The knowledge of ſuch works will prove no mean commentary on the ALL PERFECT WORD OF LIFE, no feeble aſſiſtance to praiſe and adore the AUTHOR of every bleſſing. Such practical knowledge forms the true riches of the human mind, raiſes man in the ſcale of intelligent beings, and may deſervedly claim attention from thoſe who are moſt elevated in rank, and moſt amiable in diſpoſition.

In true philoſophy Your Royal Highneſs will diſcover that there is nothing to be feared; it will always be found the firm friend of religion and order. It does not degrade the beſt expectations of man, by deriving them from ignorance and ſuperſtition, or by queſtioning the BEING and GOODNESS of Him who governs all: it does not undermine or aſſault the fair ſtructure and mutual dependance of civil ſociety, by infuſing the ſpirit of ambitious diſcontent, and introducing the principles of levelling equality.

May

May health and happineſs be Your Highneſs's portion in time, preparatory to the fuller bleſſings of eternity: may You ſee Your Honoured Father's extenſive and extending realms flouriſhing in proſperity and peace, neither ſeduced by falſe philoſophy, nor convulſed by democratic violence.

I am, with the greateſt reſpect,

MADAM,

Your Royal Highneſs's

Moſt obliged,

And moſt humble Servant,

GEORGE ADAMS.

PREFACE.

THE plan of this work firſt occurred to me about twenty-five years ago; I was then for a ſhort time in France and Switzerland, an eye-witneſs to the zeal and induſtry with which principles were there propagated under the veil of philoſophy, that are ſubverſive of all order and religion. I obſerved that philoſophical ſocieties were formed and forming to extend the influence, and to augment the importance of writings directly oppoſed to divine revelation.

It was evident from the works of theſe pretenders to philoſophy, that they *inveſtigated nature* only with a view to darken the mind, and prevent mankind from conſidering any thing as real, but what the hand could graſp, or the corporeal eye perceive. For you find them continually embracing every opportunity to ridicule our belief in Moſes and the prophets, and cenſuring us for admitting the evidences, or believing the truths of revelation; though it is a revelation which juſtifies itſelf from the creation of the world, which declares every truth that a wiſe man would wiſh to hear;

though it is ſupported by divine authority, and confirmed by all the aſſurances that human teſtimony can afford, or the rational mind require.

Alarmed at what I ſaw, and what I read, it appeared to me of the utmoſt importance to contrive means effectually to repel notions ſo pernicious to mankind, and ſo repugnant to truth. I conceived that the beſt method of defeating their deſtructive purpoſes, and depriving them of their baneful influence, would be by ſhewing that they were neither friends to philoſophy, nor had any right to the title of philoſophers; that this end would be anſwered by exhibiting a ſyſtem of philoſophy, which ſhould point out their errors, and ſhew that no operation in nature would authorize the concluſions that they had attempted to deduce; that *phyſics*, properly underſtood, would ever go hand in hand with religion, and all it's branches converge in GOD, the center of all truth, the ſource of all perfection.

With theſe views, I began to collect materials for ſuch a work. But on my return to England the tenets of theſe men and their practices being removed from my view, I laid aſide the deſign, nor did I think of reſuming it, till I ſaw the attempts that were made here to propagate the ſame principles by the ſame means; till I ſaw a philoſophical ſociety publiſhing tracts hoſtile to good order, and the beſt intereſts of mankind; till I had reaſon to think that men were *penſioned* by republicans, and brought forward in various ſituations to

give

give credit to their party; till it was publicly avowed, that the men who were purſuing here the ſchemes that have made France a ſcene of ruin and deſolation, "were known to be *philoſophers*, and friends of humanity, *ſuperior* to the creed of any ſect, and *indifferent* to the dogmas of any popular faith." It was then high time to ſhew, that true philoſophy was no friend to their principles; for in a proper ſenſe, it implies a love of wiſdom; and it's end is to promote truth, and diſſeminate happineſs; whereas modern philoſophers make it the ornament of folly, the badge of infidelity, the road to anarchy and rebellion.

To anſwer theſe great purpoſes, I reſumed my plan, and have endeavoured to render the uſeful and important truths diſcovered by natural and experimental philoſophy familiar and eaſy; to bring together that knowledge which is diſperſed in many volumes; and to concenter in one work the labours of the wiſe men of different countries and ages.

It has been my intention to render this work a ſource of uſeful and active entertainment to young perſons; and at the ſame time that it opened their minds to enlarged views of nature, and the univerſe, it ſhould point out the true methods of reaſoning in philoſophy, and teach them to diſtinguiſh what is ſound and ſolid therein, from what is hollow and vain; that it ſhould lead them, from a conſideration of the works of GOD, to acknowledge and reverence his power, wiſdom, and goodneſs; and prove that natural philoſophy

ſophy affords no ſupport to the wretched ſyſtem of materialiſm, but concurs with religion in endeavouring to enlighten the mind, to comfort the heart, to eſtabliſh the welfare of ſociety, and promote the LOVE OF ORDER.

I wiſhed ſo to execute this work, that while on the one hand it inſtructed thoſe who know nothing of theſe delightful ſciences, it might on the other not be uſeleſs to thoſe who are more converſant in them, by preſenting the ſubject in a point of view in which it has been ſeldom noticed by other authors, and treating of ſome branches that have been altogether neglected by the writers on natural philoſophy. Whether I have been ſo happy as to ſucceed in my deſigns; whether I have been able to place theſe ſubjects in a clear and plain light, and thus open a wider gate to the fair field of knowledge, muſt be left to the deciſion of an intelligent public.

For my own part I can ſay, that I have endeavoured by every labour of inquiry, and induſtry of reſearch, by arrangement and method, to convey in a clear and conſpicuous manner a general knowledge of the ſtupendous operations that are carrying on in nature. The ſubject is indeed ſometimes varied by digreſſion, and the reader is now and then carried back into ancient days; but this is never done but with a view of conveying further inſtruction, or rendering the ſubject more obvious. Some repetitions will alſo be found, but ſeldom except where a clearer explanation

occurred, or a further application is purſued.

If any juſtification be neceſſary for treating of divine matters in phyſical books, it may be vindicated by the examples of the firſt and wiſeſt men the world ever produced: among theſe our great *Newton*,* who held it proper to treat of God and his attributes in natural philoſophy. "And every wiſe and good man muſt wiſh to ſee the relation between divinity and philoſophy farther opened and better eſtabliſhed."

As I do not wiſh to incur the charge of plagiariſm, with pleaſure I acknowledge the aſſiſtance I have received from different authors. As I have uſed an unreſerved freedom in ſelecting from their works whatever would anſwer my purpoſe, I have ſubjoined a liſt of the principal ſources of my own knowledge. To the *Rev. Mr. William Jones, F. R. S.* I am particularly indebted; his capacious mind and active powers graſp with no common energy every branch of ſcience; and there are few that he has not enriched by novelty of obſervation, or illuſtrated by perſpicuity of manner. To *Mr. de Luc, F. R. S. &c.* I am alſo under great obligations; his works have been long known and highly eſteemed, and will continue ſo as long as ſound reaſoning and phyſical logic have any claims to the attention of mankind.

If

* Et hæc de Deo; de quo utique ex phænomenis differere, ad philoſophiam experimentalem pertinet. Newt. Prin. Schol. Gener.

If my health permits, at ſome future (and diſtant) period, I mean to preſent my countrymen with an abridgment of his works, particularly thoſe parts which have relation to the ſyſtem of Mr. le Sage. Theſe gentlemen as authors are not the only perſons to whom I am indebted; I owe many obligations to my friend the *Rev. Mr. Agutter, M. A.* for ſome valuable communications, and much kind aſſiſtance.

Conſcious that my intentions have been ſincere, to advance ſcience, to promote truth, happineſs, order, and peace; I may expect ſome approbation from thoſe I wiſh to inſtruct, and may hope for ſome indulgence from thoſe who are peculiarly converſant in theſe ſubjects. The wiſer men are, the more candid they become, and the leſs apology will they require for my imperfections or overſights as a writer and philoſopher. I may not have enjoyed thoſe advantages of education which others poſſeſs; I could not poſſibly repeat every experiment which is here noted. During the compoſition of theſe Lectures I have had to attend to the grateful calls of daily buſineſs, and have ſtruggled with much weakneſs and languor. The ideas of mental perfection are ſeldom if ever realized. The author is often the firſt to obſerve how much is deficient, I do not pretend to be indifferent to the judgment or the approbation of the public regarding a work which has coſt me much thought, time, and expence.

expence. I think I may ſafely recommend it to the youth of both ſexes, particularly to thoſe who are delighted and improved with the *Reflections of Sturm*: they will here find, that the ſame ſubjects are in a great meaſure continued and enlarged, but I truſt with this advantage, that they are placed on their philoſophical and mathematical foundation, are connected with other parts of the univerſal ſyſtem, are arranged in general and perſpicuous order, and may be conducive to further diſcoveries, and more accurate inveſtigations of nature.

To render this work more uſeful, I have added a copious index, and references to the figures of the plates. The references to the figures of Vol. 1 and 2, are at the end of their reſpective volumes. The references for Vol. 3 and 4, are at the end of the 4th volume. The index and plates conſtitute a fifth volume.

ERRATA.

VOL. I.

Page 13, line 21, *after* equal, *insert* in volume. P. 15, l. 24, *for* (I) *read* (d). P. 18, l. 9, *for* hail *read* rain. P. 97, l. 28, *for* pl. 3 *read* pl. 4. P. 231, l. 10, *for* bliſtord *read* bliſtered. P. 365, l. 32, *dele from* Therefore, *to* depend. P. 381, l. 32, *for* is, *read* it.

VOL. II.

P. 13, l. 20, *read* of the new; *in the ſame line read* emiſſion of the. P. 60, l. 16, *for* leads *read* lead. P. 72, l. 3, *for* filled *read* fitted. P. 75, l. 1, *for* piſton *read* friction. P. 76, l. 18, *for* condenſion *read* condenſation. P. 100, l. 3, *for* lending, *read* lends. P. 149, l. 2, *dele* is. P. 180, l. 1, *for* fig. 12, pl. 2, *read* fig. 2, pl. 2. P. 194, l. 8, *for* fig. 15 *read* fig. 15*. P. 206, l. 12, *for* ſoint, *read* joint. P. 286, l. 18, *for* fig. 1 *read* fig. 10, pl. 3. P. 390, l. 15, *for* fig. 11 *read* fig. 14, pl. 7. P. 485, l. 6, *for* fig. 13, pl. 6, *read* fig. 13*, pl. 6. P. 509, l. 20, *after* diagram *insert* fig. 16, pl. 7.

VOL. III.

P. 62, l. 24, *for* he *read* the. P. 177, *for* fig. 92, *read* fig. 9, pl. 2. P. 281, *by ſome miſtake the figure here referred to has not been engraved; the ſubject is ſo clear, that it will not be of material conſequence.* P. 293, *for* fig. 4, pl. 5, *read* fig. 4, pl. 3. P. 319, *for* fig. 2, pl. 6, *read* fig. 3, pl. 5. P. 449, l. 4, *for* 9⁹ *read* 49. P. 502, l. 7, *inſert* fig. 9, pl. 3.

VOL. IV.

P. 46, l. 17, *for* miles *read* minutes.

A LIST of the principal AUTHORS, to whom I am indebted for my information on the ſubject of theſe Lectures.

Adams	Eſſays on the Microſcope, 4to.	*London*, 1787.
	Aſtronomical and Geographical Eſſays. — —	*London*, 1790.
	Eſſay on Viſion. —	*London*, 1792.
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	Diſſertation on the Barometer.	*London*, 1790.
Atwood	Analyſis of a Courſe of Lectures.	*London*, 1784.
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Buat	Principes d' Hydraulique, 2 vol. 8vo. — —	*Paris*, 1786.
Boſſut	Traité d' Hydrodynamique, 2 vol. 8vo. — —	*Paris*, 1771.
Briſſon	Traité elementaire de Phyſique, 3 vol. 8vo.	*Paris*, 1789.
Cotes	Hydroſtatical Lectures. —	*London*, 1738.
Chaptal	Elements of Chemiſtry. —	*London*, 1791.
Camus	Elemens de Mechanique, 2 vol. 8vo.	1766.
Du Chaſtellet	Inſtitutions Phyſiques. ———	1742.
De la Caille	Elements of Aſtronomy tranſlated by Robertſon. ——	*London*, 1750.
	Leçons Elementaire de Mechanique. — ——	1764.
	Leçons Elementaire d'Optique.	*Paris*, 1766.
Crawford	Experiments and Obſervations on Animal Heat. —	*London*, 1788.
Cavallo	On Magnetiſm. —	*London*, 1787.
Dalton	Meteorological Obſervations.	*London*, 1793.

Deſaguliers

Desaguliers	Course of Experimental Philosophy, 4to. 2 vol. —	1744.
	Translation of s'Gravesande's Mathematical Elements of Philosophy, 2 vol. 4to. —	1747.
Euler	Lettres à une Princesse d'Allemagne, 3 vol. 8vo. —	1775.
Eeles	Philosophical Letters. *London*,	1771.
Emerson	Mechanics. — *London*,	1793.
Goldsmith	History of the Earth, &c. 8 vol. 8vo. —	1774.
	Survey of Experimental Philosophy.	
Helsham	Course of Lectures in Natural Philosophy. —	1775.
Harris	Treatise of Optics. —	1775.
Hutton	Dissertations on Philosophical Subjects.	
Jones Rev. Wm.	Physiological Disquisitions, 4to. *London*,	1781.
	Essay on the First Principles of Natural Philosophy, 4to. *Oxford*,	1762.
Kirwan	Estimate of the different Temperature of different Latitudes. *London*,	1787.
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De la Lande	Astronomie, 4 vol. 4to. *Paris*,	1792.
Lavoisier	Elements of Chemistry. *Edinburgh*,	1790.
De Luc	Recherches sur les Modifications de l'Atmosphere, 4 vol. 8vo. *Paris*,	1784.
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Maclaurin	Account of Sir Isaac Newton's Discoveries. — *London*,	1755.
Martin	Gentlemen and Ladies Philosophy, 2 vol. 8vo. — *London*,	1775.
	Philosophia Britannica, 3 vol. 8vo. *London*,	1771.
Nicholson	Introduction to Natural Philosophy, 2 vol. 8vo. —	1787.

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Nicholſon	Firſt Principles of Chemiſtry.	1790.
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Prevoſt	De l'Origines des Forces Magnetiques. —— *Geneve*,	1788.
Rowning	Syſtem of Philoſophy, 2 vol. 8vo. *London*.	
Rutherforth	Natural Philoſophy, 2 vol. 4to. *Cambridge*,	1748.
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Smith	Complete Treatiſe of Optics. *Cambridge*,	1738.
Shebbeare	Practice of Phyſic, 2 vol. 8vo. *London*,	1755.
Tatham	Chart and Scale of Truth, 2 vol. 8vo. — *Oxford*,	1790.
Tucker	Light of Nature purſued, 7 vol. *London*, 1748,	1777.
Vince	Plan of a Courſe of Lectures. *Cambridge*,	1793.

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LECTURES ON NATURAL PHILOSOPHY.

ON THE NATURE AND PROPERTIES OF AIR.

LECTURE I.

THE earneſtneſs of your wiſhes, to know the nature and uſe of the various articles now lying upon the table before you, and which have been purchaſed for your amuſement and inſtruction, gives me great pleaſure, not only as it inſures me your attention, but as it affords me an opportunity of ſaying a word or two on a ſubject in which you are highly intereſted. It is, to encourage you to be often aſking queſtions, and inquiring into the uſe of the things that are continually preſenting themſelves for obſervation. If you ſuffered no ſubject, whether of buſineſs or amuſement, to paſs by without inquiring into the uſe or advantage it would be of, either to yourſelves or companions, you would acquire a habit of attention, you would awaken curioſity, and excite a ſpirit of inquiry; but above all you would ſtrengthen your underſtanding, and learn rightly to eſtimate the worth and value of things.

You may lay it down as a maxim, that as the eſſence of folly conſiſts in an entire want of judgment, in an ignorance of the true value of things, ſo the eſſence of wiſdom and knowledge muſt conſiſt in the excellency of your judgment, or in the juſtneſs of your knowledge of the worth and value of things. He who knows moſt of the value of the beſt things, and who forms the beſt judgment of the things which are of the moſt concern to him, has the higheſt wiſdom, and will be the happieſt man. By habituating yourſelves to a practice conformable to this maxim, you will be prevented from taking any delight in thoſe things which debaſe the mind, and are contrary to reaſon. You will not ſeek happineſs where it is not to be found, becauſe you will know that it is a treaſure hidden within you, and that you may always enjoy by a proper regulation of your tempers and conduct.

The eagerneſs with which you deſire to know the uſe of this apparatus will be conſiderably heightened, when I acquaint you with the purpoſes for which it is deſigned. It is intended to introduce you to natural philoſophy, to enrich your minds with the knowledge acquired by the labours of the great and wiſe men who lived before you, to make you acquainted with the ſcenery of nature, the ways and means made uſe of by the great author and ſupporter of your being and mine, in producing thoſe wonderful appearances you ſee in the air, the changes you obſerve in the ſeaſons, the nature of the air you breathe, and the fire which animates your frame. But this apparatus is not confined merely to an explanation of the operations of God in nature; it will inſtruct you alſo in the wiſdom he has communicated to man, and ſhew you the nature of thoſe engines which they have contrived, the action of that uſeful inſtrument the common pump will be explained, and you will

learn,

learn to know when they are well or ill conſtructed. You will comprehend the properties and principles of the ſteam engine, whoſe operations have ſo often excited your admiration; it will be too tedious to enumerate all the advantages you may acquire from this apparatus. Let me aſſure you that explaining them to your companions, and performing the operations yourſelves, will not be one of the leaſt, for by thus exerting the faculties of body and mind, both will be ſtrengthened and improved.

From natural philoſophy you will learn that the creation is but an image or picture of the divine perfection, and therefore bears a character of his *infinity* and immenſity: that this ſmall part of it which we inhabit, is but a point in compariſon of the ſolar ſyſtem: that the ſolar ſyſtem is but a point in compariſon of the vaſt regions of the fixed ſtars: that theſe ſuperior regions themſelves are but a point in compariſon of the innumerable worlds that lie perhaps hid in the boſom of immenſity: that in this point which we inhabit, we know only ſome ſuperficial qualities and properties of nature: *that*, as SIR ISAAC NEWTON ſaid, *all the diſcoveries mortals* can make, are like thoſe of a child upon the borders of the ſea, who has only broken ſome pebbles, and opened ſome ſhells, to ſee what is in them, while there lies beyond him a boundleſs ocean, of which he has no ideas: that we can never be true philoſophers till we ſee the AUTHOR of nature face to face; compare the pictures with their original; and know, by direct intuition, their mutual relation and reſemblances. Lord Bacon terms natural philoſophy, the great mother of the ſciences,* for neither the arts of ſpeech, logic, medicine, civil policy, morality, religion, &c. can be advantageouſly exerciſed, improved,

* Shaw's Bacon, vol. 2, page 376.

proved, underſtood, or inſtituted without it, and all the mechanical ſciences depend upon it.

As you are now going to engage in the ſtudy of one of the branches of natural philoſophy, a ſhort hiſtory of the origin of the word itſelf cannot but prove acceptable. When PYTHAGORAS, of whom you have already heard much, had completed the great tour of ſcience, and ſtored his mind with all the hidden treaſures of oriental knowledge, he preſented himſelf for the firſt time to the admiring eyes of Greece, aſſembled at the olympic games.

"A ſpectacle no doubt it was for univerſal admiration and reſpect; an underſtanding ſo enriched, and full in meridian vigour, was an object that his cotemporaries might look at with veneration little ſhort of idolatry. *Pythagoras* in this attitude, ſurrounded by the Grecian ſages on the field of the olympic games, whilſt every eye was fixed with rapture and delight upon one of the moſt perfect forms in nature, began to pour forth the wiſdom of his doctrine; aſtoniſhment ſeized the hearers; and almoſt doubting if it had been a mortal that had been diſcourſing, they with one voice demanded by what title he would be addreſſed. Pythagoras anſwered, that their ſeven ſages had taken the name of wiſe men, for his part he left them in poſſeſſion of a diſtinction they ſo well merited, he wiſhed to be no otherwiſe remembered or deſcribed than as a LOVER OF WISDOM;* his pretenſions did not go to the

* As the word *philoſophy* has been of late much abuſed by infidels, politicians, and divines, it may not be improper to give another definition of the word, to guard and protect it, and to ſerve as a teſt by which to try the principles of theſe different writers. "Philoſophy is the inveſtigation of truth of every kind *from thoſe principles which are peculiar and proper to itſelf, and from no other;* which principles are not to be taken up at a venture, *or framed upon ſuppoſition*, but to be ſought and found by much experience and obſervation in the nature and conſtitution of things themſelves."

the poſſeſſion of it, and if they would call him a PHILOSOPHER, he would be contented with the appellation. From this time the name of a philoſopher became a title among the learned."*

Not to detain you longer from an examination of the articles before you, I ſhall firſt give you a general deſcription of ſome of them, and tell you their ſeveral names; this will render the explanation of their reſpective uſes eaſier and more ſimple, and will enable you to make experiments with them, and explain their effects with greater facility.

The inſtrument before you is called an *air-pump*.† It is one of the moſt uſeful of all thoſe philoſophical inſtruments whoſe action depends on the air. It conſiſts of a pump or ſyringe, annexed by means of other pieces to a glaſs veſſel, and is ſo contrived that by moving a rod up and down, the air contained in the receiver may be extracted. It is formed of five principal parts: 1. The barrel. 2. The piſton moveable in the barrel. 3. Two valves or openings ſo contrived as to prevent the air returning back again. 4. The plate of the pump on which the veſſels are to be placed, that the air may be extracted from them. 5. A guage or apparatus for meaſuring the degree of exhauſtion. 6. A ſcrew for occaſionally admitting the air when required.

The neceſſary requiſites of a good air-pump are, 1. That it exhauſt or rarify the air as much as poſſible. 2. That this be effected in the leaſt poſſible time. 3. That there be a guage affixed to the pump, to aſcertain with accuracy the degree of rarifaction.

Before I explain the conſtruction of the pump, I ſhall place before you a few models of valves, (*fig.* 4, 5, 6, 7, 8, *pl.* 1.) on different conſtructions, that you may have a clearer notion of their nature and uſe. By *a valve* is always underſtood ſome

 ſubſtance,

* Obſerver, No. 10. † See *fig.* 1, 2, 3, *pl.* 1.

ſubſtance, ſo placed over a hole, as to permit a fluid to paſs through one way, but not the other way, or back again.

A *ſtop-cock* is a ſpecies of valve, for by turning it one way, it lets a fluid paſs through a pipe, &c. but by turning it about one quarter round it ſhuts up the paſſage. When the hole in the moveable piece or cock coincides with the bore of the pipe, there is a free paſſage for the fluids communicating therewith, but when the cock is turned the veſſel is ſtopped.

The glaſs veſſels to be placed on the pump are called *receivers*, ſome of them are open at top, the others are cloſed.

To gain a clear idea of the action of the air-pump, it will be neceſſary to take it in pieces. You may now ſee that the barrel is made very cylindrical and ſmooth; the piſton, which moves up and down, is made to fit it ſo exactly as to permit no air to paſs between it and the barrel, and yet to move up and down with eaſe; the bottom of the piſton when down lies as cloſe as poſſible to the lower valve, in order to prevent any air remaining between them. You obſerve that in the piece ſcrewed to the bottom of the piſton, there is a hole, coinciding with one that goes through the piſton; over this hole a ſmall piece of oiled ſilk is tied, which is the piſton valve; it opens upwards to give a paſſage to the air from below. In the braſs plate on the bottom, you ſee another hole with a valve on the top; by this there is a paſſage for the air from any receiver placed on the plate of the pump to the cavity of the barrel at bottom; for the large plate of the pump is perforated with a hole, to meet the laſt mentioned one. Theſe few parts are all that are eſſential to the pump, and will be ſufficient to give you a very clear notion of the principles of thoſe that are made in a complex form.

To

To work the pump, the piſton is placed at the bottom of the barrel, and then lifted up; we ſuppoſe it to be ſo well fitted as to leave little or no air beneath; conſequently, on lifting it up you raiſe the column of air that ſtands over the piſton, and leave a cavity or ſpace below in a great meaſure void of air, ſuppoſing that none could enter into this ſpace through the valve in the plate of the pump. But as the air is very elaſtic, (as I ſhall prove to you hereafter) that which is in the receiver ruſhes through the lower valve into the void ſpace in the barrel, till what is there, and in the receiver, become equally denſe; by this means the quantity of air in the receiver is leſſened, and as what remains ſtill occupies the ſame ſpace, it is ſaid to be rarified or leſs denſe.

This is one half of the operation; in the next place, the piſton is to be carried down to the bottom of the barrel; by raiſing the piſton I brought ſome of the air out of the barrel; by depreſſing the piſton I ſhall get it out of the barrel alſo, and thus get rid of it quite; for by forcing the piſton down, the air contained below it in the barrel (as it cannot return through the valves at the bottom of the plate,) is condenſed by the piſton, till it acquires elaſticity enough to force open the valve in the piſton, and make it's eſcape into the common air, from whence it cannot return, being prevented by the valve. Thus a part of the air in the receiver is extracted, and by continuing the operation as much will be taken therefrom as may be required.

By means of the air-pump and it's apparatus, you will ſoon become acquainted with the nature and properties of air. AIR is a fluid into which you are plunged the moment you are born, and without which you would in a moment be deprived of life. The nature of a fluid ſo important, ſhould certainly engage the attention of every rational being; for

no ſubſtance has a more univerſal influence on the general courſe of nature. The varieties in it's temperature and weight are continually agitating our frame; to the action of theſe changes on our bodies we may attribute many of our ſenſations, both irkſome and pleaſant. Indeed we have always ſomething to hope or fear from the viciſſitudes of which it is ſuſceptible. It contributes to the formation of hail, and ſuſtains the clouds. Plants grow and are nouriſhed by it. Without the air, there would be neither ſound, nor voice, nor language, all fire would be extinct, animals would periſh, and the whole world would languiſh and decay. It is almoſt impoſſible for you to think with indifference of the wonderful effects occaſioned by this inviſible agent. If your mind is capable of admiring theſe effects, it will not be inſenſible to the pleaſure that is to be derived from a knowledge of their cauſes.

It is ſo pleaſing to contemplate the firſt dawnings of improvement in ſcience, and to ſee them riſing gradually to perfection, through the ſucceſſive labours of innumerable minds; that I cannot refrain from giving you a ſhort hiſtory of the air-pump.

The famous experiment of Torricellius, (to be explained in the next lecture) gave riſe to the air-pump, and led the *Florentine Academicians* to contrive an inſtrument to procure a vacuum. For this purpoſe they filled a veſſel with quickſilver, and then emptied it, taking care to prevent the air from entering while the quickſilver was going out: this inſtrument being very inconvenient, as well as imperfect, was ſoon laid aſide.

Otto de Guericke, an ingenious magiſtrate of Hamburgh, invented the air-pump in 1654, and made the firſt public trial thereof about the ſame time at Ratiſbon, before the Emperor of Germany, and ſeveral of the electors, who were highly delighted with the curious experiments exhibited by

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it. An account of theſe was ſoon after publiſhed by Scottus, a learned Jeſuit. In 1672 Otto de Guericke gave an excellent narrative of his own experiments: the inſtrument was, however, ſtill awkward and very imperfect. In order to try experiments with it, they were obliged to place their glaſſes, veſſels, and other ſubſtances under water, to prevent the air from re-entering.

It was afterwards ſo much improved by *Hooke*, the rival of Newton, and by the famous *Boyle*, and was applied by the latter to ſuch uſeful purpoſes, and opened in his hands ſo rich a mine of natural knowledge, that the invention has often been attributed to him, and the vacuum made by the air-pump is ſtill called the *Boylean* vacuum, in contradiſtinction to that of Torricellius. Subſequent improvements have been made by Meſſrs. Graveſande, Nollet, Smeaton, Haas, and Cuthbertſon; but the laſt and moſt perfect is that of the Rev. Mr. Prince, of Boſton in America, to which I have given the name of the *American Air-pump*. It would be unneceſſary minutely to deſcribe the reſpective merits of theſe improvements; but it would have been highly improper to leave you altogether unacquainted with the names of thoſe who have improved the inſtruments of ſcience, and of whoſe labours we are now reaping the benefit.

It is a duty we owe ſociety to commemorate the benefactors of mankind: and I therefore feel great pleaſure in laying before you a ſhort ſketch of the character of Mr. Boyle, whoſe unexceptionable integrity, extenſive charity, and ſingular piety, did great honour to philoſophy; no one ever took more pains to promote natural knowledge in all it's branches; among theſe the doctrine of the air afforded him ample field, and he cultivated it with ſucceſs; he examined objections with patience, and refuted them without oſtentation. The world he conſidered

confidered as the temple of God, and "man (to ufe his own words,) as born the prieft of nature, ordained (by being qualified) to celebrate divine fervice, not only *in*, but *for* it." Not fatisfied with having promoted the belief of a Deity, and the evidence of true religion, in the greater number of volumes compofed by him during the courfe of a laborious life, he has taken care by his will to perpetuate a fucceffion of advocates for it. Such a man, we muft allow to be an ornament to his own age and country, and a public benefit to all times and nations. He feems to have been a heavenly fpirit in a human form defcending from above, to furvey the wonders of this lower frame, and from thence, as from a new fubject, to raife in himfelf and others a new fource of adoration and gratitude, and new fongs of love and praife.

As you have now attained a general idea of the fabric and contrivance of the air-pump; I fhall proceed to inveftigate the properties of the air itfelf by means of this inftrument.

OF THE RESISTANCE OF AIR.

The form of air is not vifible, yet the fubftance and action thereof is evident to the reft of our fenfes. This bladder which I am going to fill with air, will be very different when filled, from what it is in it's prefent ftate; it may now be rolled up and twifted almoft into any form, but when I have filled it, it is capable of refifting a confiderable preffure.—It is now filled, and you will find that fcarce any force you can exert will bring it together. You cannot indeed fee the air in the bladder, but you can feel it's refiftance, in the fame manner the particles which give energy to the hurricane are invifible, but fatal experience evinces their power.

Here is a fyringe with a folid pifton; I have ftopped the bottom, that the air contained between the

the piſton and the bottom of the ſyringe may not eſcape. This air, when the piſton is at a certain depth, will reſiſt ſo powerfully, that if the materials do not give way, no force whatever will bring the piſton down. Try it, and you will find on puſhing it down, that it ſeems to work as if againſt a very ſtrong ſpring.

Here are two glaſs veſſels, ſuch as are ſold in the ſtreets by the Italians; theſe will exhibit another proof of the reſiſtance of the air. This in my hand has had the air extracted from it, the air remains in the other. I lift the exhauſted one up, and the water falls upon the glaſs in which it is incloſed like a piece of iron, with a ſmart noiſe, from whence it has been named the *philoſophical hammer*; while in this, where there is a bed of air to fall on, it ſcarce makes any noiſe. Artiſts are accuſtomed to judge of the goodneſs of the vacuum in barometers, &c. by the ſmartneſs of the ſound made by the quickſilver.

Cuſtom has rendered the contact of air ſo familiar to us, that you muſt reflect, before you can be ſenſible of the actual impreſſions it makes upon you. Being conſtantly ſurrounded by the air, we do not conſider the continual force it oppoſes to all our motions; but if we could be taken out of the atmoſphere, and were to return to it again, we ſhould then perceive without reflection, that the air touches us on all ſides, as we feel that the water touches us when we plunge into it.—I take this empty glaſs veſſel, and plunge it perpendicularly into a jar of water with the mouth downwards, and you perceive that that part of the water which anſwers to the mouth of the glaſs veſſel, ſinks in proportion as the veſſel deſcends, for the veſſel contains a column of air, which oppoſes the entrance of the water, though it's reſiſtance is not powerful enough to exclude it intirely. Hence you

ſee,

ſee, why a veſſel cannot be filled with water by plunging it with it's orifice downwards; why a funnel, if the pipe fits cloſely to the neck of a bottle, is not convenient for pouring of liquor; for in order to put the water or wine into the bottle, the air muſt paſs between the neck and the funnel; but when the neck is ſo narrow, that there is not room for a free paſſage, at the ſame time, for the liquor to go in and the air to go out, it muſt be brought about ſucceſſively. We are apt, indeed, to conſider every thing as empty which is only filled with air; but the experiments you have ſeen, have ſhewn the impropriety of this conſideration, by proving that they are filled with a reſiſting ſubſtance.

OF THE WEIGHT OF THE AIR.

You have often heard, perhaps, made uſe of the expreſſion, "as light as air;" but light as it is, it is heavier than you imagine, and it's weight is the cauſe of many wonderful effects in nature. That it has weight, I ſhall prove, by ſhewing you that a veſſel is heavier when full of air, than when the air is extracted from it. For this purpoſe, I have a bottle furniſhed with a ſtop-cock; I weigh this accurately while full of air. I ſhall now extract the air out of it, and prevent it's re-entrance, by turning the ſtop-cock: on weighing it again, you ſee it is conſiderably lighter than it was before, and conſequently has loſt weight by the extraction of the air.

You have now learnt that the air has weight; by filling the bottle when emptied of air, with diſtilled water, and then weighing it again, you will find it's ſpecific weight, that is, you will compare a given quantity or bulk of air, with the ſame volume or bulk of water, and thus diſcover the difference between them.

To be more particular, I fill this flaſk, when the air is exhauſted from it, with water, and weigh it. I ſubtract from this weight, the weight of the flaſk, (without air,) the deficiency is the weight of the water. A cubic inch of water has been found to weigh ſo many grains; dividing therefore the weight of water, by this number of grains, gives me the cubic inches contained in the flaſk.

I have now obtained, 1. The weight of the flaſk without air. 2. The number of cubic inches contained in the flaſk. 3. The weight of this number of cubic inches of water. 4. The weight of the ſame number of cubic inches of air.—The relation between the two laſt numbers gives us the ſpecific gravity of water and air; for the ſpecific gravity of air is to that of water, as the weight of a cubic inch of air is to that of a cubic inch of water. We obtain the weight of a cubic inch of air, by dividing the weight of air in the flaſk by the number of cubic inches contained by the flaſk.

About 14½ grains of air are equal to two pounds of water; therefore the proportion is as 1 to 800.

Abſolute exactneſs is not attainable by this method; it is however ſufficient for every common purpoſe. The height of the barometer and thermometer ſhould always be noticed at the time the experiment is made, as a variation in theſe will occaſion a difference in the reſults. The weight of the elaſtic fluids, of whoſe nature we ſhall ſpeak hereafter, may be obtained in the ſame manner.

Of the Pressure of the Air.

As you have ſeen that the air has weight, and conſequently preſſes upon all bodies that are contiguous to it, you will be leſs ſurprized at ſome of the effects occaſioned by this preſſure. I place this glaſs veſſel upon the plate of the pump, from which you may remove it with the utmoſt facility, becauſe there

there is under it a maſs of air of equal denſity with that which ſurrounds it; the internal air is a counter-ballance to the column of air upon the top of the receiver. I now work the pump, and thereby take out or exhauſt the air from under the receiver, and thus remove the counter-preſſure; the receiver will then be preſſed down upon the plate of the pump by the whole weight of the atmoſphere incumbent on it's ſurface. It is done, and you will now find it very difficult to ſeparate the receiver from the plate, to which it is fixed down with a force equal to as many times 15 pounds, as there are ſquare inches covered by the opening at the mouth of the receiver. If the receiver be large, the weight of the preponderating column is enormous. You cannot, I ſee, ſeparate the receiver from the plate; I will, therefore, re-admit the air, by turning this ſcrew, the ballance will again be reſtored, and the air preſſing as much upwards againſt the inward parts of the receiver, as the outward parts are preſſed by the external air, the receiver may be eaſily removed.

The natural propenſity of the human mind to know the cauſe of every effect, often leads men into errors, and makes them ſatisfied with a word which does not remove their ignorance. It is thus that ſome have ſaid, the glaſs was held down by *ſuction*, without explaining what they meant by ſuction, or ſhewing how it was produced. We ſhall, however, prove to you by the next experiment, that the glaſs is not held down by ſuction. I take this braſs plate, put an oiled leather on it, and place it on the plate of the pump; I then ſuſpend this ſmall receiver on the hook under the larger one, and place the large one in ſuch manner on the plate, that the ſmall receiver, when let down, will come on the ſmall plate: (*fig.* 17, *pl.* 1.) upon working the pump, the air will be exhauſted from both

both receivers. Let us now confider the circumftance; there is no air under either glafs, all is free within, but the outer glafs is held down by the preffure of the external air, whilft the fmall glafs having no air to prefs upon it, continues loofe, and may be drawn up and down at pleafure. Admit the air into the receiver, and the large one will be fet at liberty, whereas the fmall one will be preffed down upon the plate; and this, not from fuction, for it continued loofe whilft I was pumping, but the internal air or prop being taken away, the external preffes upon it, and keeps it down.

There are few experiments which are more decifive againft the common opinion of fuction than that which is made with the inftrument called *a double transferer. (fig.* 11, *pl.* 2.) Screw the end of the middle pipe into the hole of the pump, and turn the cocks d, G, H, fo as to open the communication between the pipes and the pump. Place a receiver upon one of the plates (g), taking care that the communication with the other is cut off by turning the cock (H) connected therewith, exhauft the air out of the receiver, then turn the cock (I), which connects the whole with the pump, to prevent the air from re-entering, and unfcrew the apparatus from the pump: now put a receiver upon the other plate, and this will continue loofe on the plate as long as it remains full of air: turn the cock (H) belonging thereto, to open the communication, between this and the other receiver, and the air in the laft having nothing to act againft it's fpring, will rufh into that which was exhaufted, until it be of equal denfity in both, and they will be held down with equal forces to their plates, by the preffure of the atmofphere, though each will be kept down with only one half of the preffure that acted on the firft when exhaufted of it's air.

Here is a glafs open at both ends. I took a wet

bladder, and ſtretched it over one of theſe ends, tied it faſt, and let it dry. I now place it on the plate of the pump; *(fig. 14, pl. 1:)* while the air preſſes the bladder equally on both ſides, it lies even and ſtrait; but as ſoon as I begin to exhauſt the air, you ſee it is preſſed inwards, and is quite concave on the upper ſide; in proportion as I exhauſt the air, the bladder is more ſtretched; it will ſoon yield to the incumbent preſſure, and burſt with a loud exploſion. You obſerve that, when the bladder was much preſſed down, it recovered it's ſmooth even ſituation, as ſoon as I let in air to ſupport it; but no ſooner did we take away this aſſiſtance, than the bladder burſt. As the fibres of a bladder are very ſtrong, this experiment will not always ſucceed, and you will often find it neceſſary to facilitate the rupture, by preſſing the bladder with your finger, or the point of a knife: to avoid this, and render the experiment more certain, I macerated the bladder, and then took off ſome of the ſkins of which it is compoſed; being thus rendered thinner, it has ſucceeded perfectly to our wiſhes.

You aſk me, with propriety, why the weight of air does not break the receivers as it burſts the bladder? The ſtrength of the receivers is derived from their circular form; the arched figure prevents them from giving way inwards, for if they were made with flatted ſides like this ſmall thin bottle, the external preſſure would break them to pieces when the air was removed from the inſide. This ſquare bottle has a valve at the neck opening outwards; I ſet it on the plate of the pump with a cage over it, and a receiver over both, *(fig. 2, pl. 3,)* and exhauſt the air; that in the bottle will come out through the valve: the air is now exhauſted, and I ſhall let it in again ſuddenly; the valve will prevent any from getting into the bottle. The receiver is now

now full of air, and you ſee the bottle has burſt into innumerable pieces, with a loud exploſion; for being deprived of the internal ſupport, it was incapable of ſuſtaining the weight of the atmoſphere. The noiſe in theſe experiments has ſtruck you with aſtoniſhment, it is therefore neceſſary that I ſhould explain the reaſon to you; it is occaſioned by the quantity and velocity with which the air enters the vacuum. Mr. Papin has calculated, that the air enters a vacuum with a velocity that would carry it through 1300 feet in a ſecond of time. When I pull off the top of this tooth-pick caſe I rarify the air, for while I am opening the caſe, the capacity thereof is increaſed, the air which before occupied this ſhort ſpace, now occupies a larger; and the velocity and force required to reſtore it in both pieces to it's natural ſtate, occaſions the noiſe. Other inſtances will occur, which you may explain in the ſame manner.

When I ſtretch out my hand, with the back of it upwards, I do not feel the weight of the air which preſſes upon it, becauſe the lower air preſſes the palm of the hand as much upwards, as the incumbent column preſſes the back part downwards; and theſe two mutual and contrary forces deſtroy each other, ſo that neither of them is felt. But if you place your hand upon this receiver, while I exhauſt the air from below it, and thus remove the air which preſſed upward againſt the palm of the hand, whilſt the external air preſſes upon the back part of it, you will find your hand preſſed downwards with force enough to give you pain, and make you feel the weight of the incumbent atmoſphere. Thus as we ſeldom know the bleſſings that ſurround us till we are deprived of them; ſo in the preſent caſe, we were not ſenſible of the weight of the ambient fluid, till a part of it was taken away, and the preſſure was not ſenſible till the

counteracting pressure was removed. To lift your hand from the receiver when the air is exhausted from under it, you must exert a force capable of raising the column of air incumbent on it; now this column is equal in weight (as will be evident in the next lecture) to a cylinder of quicksilver, whose base is of the same size as the mouth of the receiver on which your hand is laid, and whose height is about 30 inches; of the weight of such a column, you may form some idea by lifting up this small bottle with quicksilver; at the same time that the hand is thus forced down, the pressure is taken off from that part which is exposed to the vacuum; the fluids therefore flow to that part and cause it to swell, which is further increased by the elasticity of the air, a property to be hereafter noticed.

This experiment shews also, that there is a quantity of air contained in the flesh and humours of the body, and explains the nature of *cupping*. In doing this, the operator generally takes a small glass close at top, and holding it a little time over the flame of a lamp, the air is thereby rarified, and a part of it driven out; the glass is then suddenly clapped on the part to be cupped, the remaining air now cools and condenses, and the glass adheres to the flesh. In proportion to the difference in the pressures of the external and internal air, the flesh rises in the glass and becomes very protuberant, as in the foregoing experiment, and for the very same reasons: the glass being removed, the part is immediately wounded by a scarificator, which is a kind of lancet with many points. The glass is then heated a second time, and applied as before; blood and serosities are by the external pressure of the air forced from the wounded vessels into the glass, and when one has done it's office

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and drawn ſufficient, another is applied, till the intended quantity is drawn off.

The beſt way of cupping is by the exhauſting ſyringe.

It muſt be evident from what you have ſeen, that the preſſure will be greater and more ſenſible, in proportion as the mouth or opening of the receiver is larger, and conſequently you will find that your hand will be more firmly attached to the receiver, than your thumb will be to this hole in the plate of the pump.

I have tied the neck of a bladder to a ſtop-cock, which I ſhall ſcrew to the plate of the pump, and exhauſt the air from the bladder; I now turn the ſtop-cock to prevent the re-entrance of the air, and then unſcrew the whole from the pump. The bladder is transformed into two flat ſkins, ſo cloſely applied together, that the ſtrongeſt man cannot raiſe one of them half an inch from the other. When the bladders form the area of a circle ſix inches diameter, each ſide is preſſed down upon it's fellow with a force equal to 396 pounds.

This experiment is elegantly illuſtrated by the hemiſpheres, which are uſually termed the *Magdeburg Hemiſpheres*, (*fig.* 20, *pl.* 1,) as being the invention of Otto de Guericke, of Magdeburg. I apply theſe hemiſpheres together, with an oiled leather at the place where they ſhut; they are now eaſily ſeparated, and will moſt probably fall aſunder by their own weight. I ſcrew them to the pump, turn the ſtop-cock, and then exhauſt the air from between them; they now (as you find) adhere ſtrongly together, with a force which requires about 15 pounds for every ſquare inch in the circle. If the air be re-admitted, they will fall aſunder as before, for the air reſtores the equilibrium; before it's admittance, the action

 within

within was weaker than the action from without, and the effect ceases as soon as the former is made equal to the latter.

To shew this in another way, I exhaust the hemispheres as before, turn the cock to prevent the re-entrance of the air, then suspend them to this hook under the receiver, and place the whole on the pump. What do you think will be the consequence, if I exhaust the air from the receiver? You know they are kept together by the air that incompasses them in the receiver. If then I should take away this air, there will be nothing to oppose their coming asunder. I have exhausted the air from about them, and you see with what ease they are separated.

This small instrument *(fig. 22, pl. 1,)* is a model on a small scale of a common water pump, and will serve to shew you why at every stroke of the common pump, the water in the well rises in the pipe below till it arrives at the cistern, and then runs out. The brass tube represents the barrel of the pump, the lower tube the pipe, and the water in the bason that of the well. I raise the piston, and you see the water follows it, rising at every stroke till it has reached the cistern and then runs out. To shew you that this effect arises from the pressure of the air, I place the pump on this receiver, and put it with the jar of water on the plate of the air-pump; I draw out all the air from the receiver, and then raise and work the piston, but the water does not rise, as there is no pressure of air to produce that effect; a clear proof also that pumps *do not act by suction.*

This plate and stop-cock is called a transferrer. *(fig. 12, pl. 2.)* I screw the stop-cock to the pump, and then this pipe on the plate of the transferrer, on which I also place an oiled leather, and then a receiver on the leather. Exhaust the

 air

air from the receiver, and then turn the ſtop-cock to prevent the re-entrance of the air; now unſcrew the whole, and hold it over the pail of water, ſo that the mouth of the ſtop-cock may be under water; turn the ſtop-cock, and the preſſure of the air will force up the water into the receiver, and form a very pleaſing fountain.

Other experiments will confirm what you have already ſeen, by ſhewing you that a quantity of a fluid as heavy as water will not ſink in the atmoſphere, unleſs the air have liberty to preſs on it's upper ſurface.

I ſlip a piece of paper on the mouth of this conical glaſs which is filled with water; I then apply my hand to the top of the glaſs, and invert it: I withdraw my hand, the water remains in the glaſs ſupported by the preſſure that the air exerciſes upwards. The ſides of the inverted glaſs prevent the air from preſſing on the upper part; but it has free acceſs underneath, and it's preſſure is evident by the concavity of the paper. The water reſts on the paper as a common baſe, which keeps the ſurface uniform, and prevents the water from oſcillating, and thus forming a paſſage for the air; becauſe when one part of the column of water becomes longer than the reſt, it is heavier, and therefore deſcends; by this means the air gets room to aſcend in the place of the deſcending water, and a general preſſure taking place, the glaſs is ſoon deprived of it's contents.

Upon this principle this fountain acts, the upper part or receiver (*fig.* 5, *pl.* 2,) is hollow, having a pipe (c) ſoldered therein, which reaches nearly to the top, on which being thruſt into a wire ſocket it reſts; it is filled by this pipe when inverted: on the under part of the reſervoir are ſeveral ſmall tubes, through which the water will flow on the admiſſion of air. The bottom part is

hollow to receive the water flowing from theſe tubes, which it does through a ſmall hole placed immediately under the orifice of the middle pipe; the area of this hole is ſomewhat ſmaller than that of all the ſmall holes taken together; when theſe therefore all run, they will yield more water than can be received in any given time. This will cauſe the water to riſe in the baſon, ſo as frequently to cover the end of the middle pipe; this prevents the entrance of the air, and takes off it's preſſure from the ſurface of the water in the reſervoir, which prevents the deſcent of the fluid through the ſmall tubes till the water at bottom has run off, and left a free paſſage for the air. By obſerving this circumſtance, you may eaſily give the word of command, and ſay when it ſhall ſtop, and when go on; this machine is called the *fountain of command.*

There are a number of ſmall holes in this tin veſſel; the mouth is not more than $\frac{1}{4}$ of an inch in diameter. Plunge the veſſel in water, and when it is full cork it up, and take it out of the water; ſo long as the veſſel remains corked, no water will come out; but as ſoon as the air has acceſs to the upper ſurface, which it will have on your taking out the cork, the water will iſſue from the ſmall holes at the bottom.

I cannot diſmiſs this part of our ſubject, without explaining a little inſtrument called the *anti-guggler*, (*fig.* 4, *pl.* 2,) formerly much uſed for decanting of liquors liable to ſediment.

As you have ſeen the neceſſity of the air's upper preſſure, to promote the eaſy and uniform flux of fluids from cloſe veſſels, commonly called *giving them vent;* you will not be ſurprized, that in decanting liquors where this upper preſſure is wanting, there ſhould happen a kind of ſtruggle, between the groſſer fluid endeavouring by it's greater

greater gravity to iſſue forth, and the air endeavouring to prevent it by it's repreſſure; hence ſuch a convulſive motion is often produced in the body of the liquor as to render it foul. To prevent this inconvenience, the anti-guggler was invented; it conſiſts of a crooked tube of metal, ſo bent, as to be eaſily introduced into the neck of moſt bottles.

To uſe this inſtrument with ſucceſs, the bottle containing the liquor to be decanted, is to be inclined a little to one ſide. Let a ſmall quantity of liquor run off, half a ſpoonful perhaps; to anſwer this, an adequate quantity of air will enter through the neck with a kind of glub, and riſe into the upper part of the bole; with your fore finger on the ring (c), and your thumb held cloſe to the neck of the pipe (A), introduce the machine into the neck of the bottle, thruſting it quite through the body of the liquor till the end (B) reaches, or is very near the bubble of air before admitted; in doing this, the liquor cannot enter into the tube on account of the incloſed air, which is prevented from eſcaping by the thumb. Take off your thumb, and an immediate vent will be given to the bottle, and the liquor will flow out ſteadily and unconvulſed.

Our next experiment will be with a *ſyringe and a leaden weight, (fig. 9, pl. 1,) at the bottom.* The piſton of this ſyringe is different from that of a common one, as it has no hole through it, nor valve; it is called a ſolid piſton. If therefore I place the piſton at the bottom of the ſyringe, ſcrew on the lead weight with a piece of leather to prevent any air getting in, and then lift up the piſton; it is evident that it leaves a vacuum below it:—let us ſee the conſequence. I let go the piſton, and it flies rapidly to the bottom on account of the air's preſſure upon it, ſo that the piſton and the lead

weight are kept together by the preſſure of the external air. I ſhall now ſuſpend it under a receiver; upon exhauſting the air, and leſſening it's force on the ſyringe, the weight of the lead will cauſe the ſyringe to deſcend from the piſton, and that lower in proportion as the air is more exhauſted; on letting in the air, it forces the ſyringe up again to the piſton.

Every experiment you have ſeen has furniſhed inſtruction, and though ſome may at firſt ſight appear of but ſmall importance, their value will be evident when you come to other branches of ſcience. Here is a large piece of cork pending from one end of a ballance beam, a ſmall piece of lead is at the other end of the beam, the lead rather preponderates over the cork; let us place this apparatus under a receiver on the pump; when the air is exhauſted, you will find the cork which now ſeems the lighteſt, proves the heavier body, and preponderates the lead. I have only moved the winch twice, and you ſee that the cork and lead are in perfect equilibrium; as I exhauſt the air, you ſee the cork preponderate the lead as far as the beam will admit; you will hereafter ſee many experiments to prove, that bodies moving in a fluid meet with a reſiſtance from it; and that in proportion as their bulk is larger than an equal bulk of the fluid. The air is a fluid; and the cork of equal weight with the lead being many times larger in bulk, will meet with ſo much more reſiſtance from the air; this reſiſtance will oppoſe a deſcent of the cork more than it does that of the lead, and will conſequently diminiſh more of it's weight. Hence when the weights are equal in air, it muſt follow, that when it is taken away, the larger bulk of cork which was before reſiſted, will prove the heavier body, as you have ſeen in the preſent inſtance.

A pair

A pair of common bellows is a philoſophical inſtrument. I have ſtopped the vents or apertures of this, and you will now find it very difficult to open the bellows; this difficulty ariſes from the weight of air on the boards, which will be removed as ſoon as I unſtop the vents, and let the air get in. When the upper part of the bellows is lifted up, the body of air is lifted up from the lower part, and the air ruſhes in at the vent at bottom to fill up the ſpace between the two boards. When I depreſs the upper board, the air preſſes againſt it, and ſhuts the valve at the vent, and not being able to eſcape that way, is forced with rapidity through the narrow hole of the pipe, and being directed to the fire makes it burn briſkly.

By the preſſure of the air, the ſuction of animals is explained. When a child ſucks at the breaſt, it performs by a natural and eaſy mechaniſm, what we perform by our machines in an aukward and laborious manner. When the mouth is applied to the breaſt, the child draws in it's breath, then ſtops the entrance into the mouth by the noſtril, and ſqueezes the nipple between his lips; the entrance of the air being excluded, and a vacuum made, the preſſure of the air upon the mother's breaſt will force the milk into the mouth, as long as the child continues to carry it off, and preſerves by it's tongue the vacuum.*

Sucking and ſwallowing are very complex operations. Anatomiſts deſcribe about thirty pair of muſcles that muſt be employed at every draught: of thoſe muſcles every one muſt be ſerved by it's proper nerve, and can make no exertion but by ſome influence communicated by the nerve. The exertion of all thoſe muſcles and nerves is not ſimultaneous, they muſt ſucceed each other in a certain order; and their order is no leſs neceſſary than the exertion itſelf. This regular train of operations is carried

* Reid on the Active Powers of Man.

carried on according to the niceſt rules of art, by the infant who has neither art, nor ſcience, nor experience, nor habit.

I have now ſhewn you with what powers of reſiſtance the air is endowed, it's comparative weight with that of other bodies, and the amazing force of this weight: this knowledge has enabled us to explain ſeveral of the common phenomena which are continually occurring to us. The further you advance, the more you will comprehend, till at laſt wherever you go you will meet with objects of information. Arts, manufactures, commerce, laws, civil government, the order and happineſs of ſociety, are the reſult of knowledge and ſcience, and participate in their improvement, and together with them make advances towards perfection, or ſink into barbarian darkneſs. Though young in years, you are put in poſſeſſion of facts, of which the ſages of antiquity were ignorant. The philoſophers of the early ages, like the "children of the world," were amuſed and ſatisfied with the obſcurity of *hypotheſis*, and the illuſions of *conjecture*; but the world riſing in years and in wiſdom, rejects ſuch methods of philoſophiſing, and confiding in facts alone, is enabled to interpret the operations in nature, and draw aſide her veil.* Indeed the *Almighty* teaches and inſtructs us in the *inviſible* things of himſelf, no otherwiſe than through the medium of the things that are made; and therefore he firſt gave us the knowledge of the natural world, that through it we might attain to that of the ſpiritual. The foot of the ladder was let down to earth, that we thereon might aſcend to heaven.†

* Sir J. Pringle's Diſcourſes. † Bp. of Norwich.

LECTURE

LECTURE II.

IT is of the utmoſt importance to your real advancement in ſcience, to avoid every ſource of error, or whatever may lead you to form an erroneous judgment. Now a true judgment can only be obtained by a profound view of nature, and a ſtrict examination into the mutual connections and dependencies of things; you will hence ſee the neceſſity of ſtrict and accurate examination, of time to acquire the requiſite knowledge, and of attention to comprehend it: for among the various ſources of error, we may reckon the precipitation of our judgment, and a preſumptuous ignorance as the principal. From theſe, as from a fruitful ſpring, ariſe obſtinacy in error, and reſiſtance to truth. A preſumptuous and untractable diſpoſition is not fitted to receive inſtruction: it is a ſtubborn and ſtony ſoil on which the ſeed ſown is intirely loſt, never producing fruit. Preſumption and prejudice are two of the great ſources of human infelicity, and yet we are too apt to indulge both in all the objects of our *will* and *judgment*, the conſequences of which is our frequent miſcarriages in the purſuits both of *happineſs* and *knowledge*.

Mankind are always ready to adopt or reject what accords with pre-conceived opinions, to make reaſon ſubſervient to prejudice, and to reject without examination, whatever is diſcordant with a received ſyſtem; thus cloſing the door of ſcience, and excluding themſelves from the benefit of light. We are told of a Florentine philoſopher, whoſe prejudices had taken ſo deep root, that he could never be perſuaded to look through one of Galileo's teleſcopes, leſt he ſhould ſee ſomething in the heavens that might diſturb his belief of the Ariſtotelian philoſophy.

The

The principal and fureft ftep towards the poffeffion of the good we feek, is our love of and affection for the object; this quickens induftry, and fharpens attention; fo that the love of truth is the beft means of fucceeding in the fearch of it. There is hardly any one who fufpects he wants this love, and yet how few are there whom their confidence does not deceive. We miftake the love of our opinions for the love of truth, becaufe we fuppofe our own opinions to be true; and yet for the moft part they have been received upon credit, and are confequently more likely to be falfe. The love of our opinions is in this cafe the love of error, and the affections being mifplaced are a greater impediment in the purfuit of truth, than if we had no affections at all concerning it.

You fhould, therefore, fet out in the fearch of truth as of a ftranger, not in fearch of arguments to fupport your own opinions, and endeavour to maintain your mind in a ftate of equilibrium, an indifference for every thing but known and well attefted truth, totally regardlefs of the place from whence it comes, or that to which it tends; being fully perfuaded that *truth*, no more than it's *author*, can fink to the level of our ignorance; but that by a proper cultivation of our reafon we may rife to truth, may reach it's fublimeft height, it's refidence near the footftool of the Almighty.*

OF THE BAROMETER OR TORRICELLIAN VACUUM.

An account of the origin of the *barometer* will be a ftrong confirmation of the truth of thefe pofitions; it's hiftory is fo connected with that of found philofophy, that the one naturally recalls the other to the mind. The torricellian experiment on which it is founded, like a river fmall in it's origin, but large

* Warburton, vol. 5, fer. 1.

large in it's progreſs, has been the happy means of ſpreading light through nations who are even yet ignorant of it's name, and been productive of benefits to thoſe who are unacquainted with it's principles.

Till the laſt century, mankind, though loaded and compreſſed by the weight of the atmoſphere, refuſed to acknowledge it's action. In vain all nature depoſed that the air was heavy and elaſtic, they ſhut their eyes to it's teſtimony. Water was raiſed in pumps, and ran through ſyphons in former times as at preſent. The ſides of a pair of bellows, whoſe apertures are cloſed, were then as now ſeparated with difficulty, children ſucked, the air entered rapidly into the lungs at each inſpiration, cupping glaſſes were uſed to raiſe the fleſh; yet notwithſtanding theſe manifeſt proofs of the weight of the air, ancient philoſophers maintained that it *had no weight, exerted no preſſure*; and explained all theſe phenomena by a *horror* which they ſuppoſed nature to have for a vacuum, contenting themſelves with thinking after Ariſtotle, that nature hated a void, and therefore made all poſſible haſte to fill it, when the art of man had made one. This is not the only inſtance that will occur in your reſearches after truth, in which you will find *words alone*, ſeparated from the ideas annexed to them, and from all explication of the operation which they effect, have been imagined ſufficient to account for phyſical phenomena, though they leave us as deſtitute of all information as we were before we uſed them.

You will be more ſurprized that mankind ſhould continue in error, after they had perceived and acknowledged that this horror had it's limits. It was not, however, till the 17th century, that they began to try what were the boundaries of this horror.

Some

Some plumbers belonging to the Duke of Florence, wanting to raiſe water 50 or 60 feet high, endeavoured to effect it by what is called a common ſucking pump; notwithſtanding they uſed all poſſible care in the conſtruction, they could not raiſe water higher than 32 feet. Tired out with repeated trials, they applied to Galileo, one of the fathers of modern philoſophy, for a ſolution of their difficulties: for if the water roſe on account of nature's horror for a vacuum, it would follow that water might be raiſed to any altitude, for why ſhould nature have a greater averſion to one height, than to another? it was therefore confidently aſſerted by ſome who had embraced this opinion, that it might be raiſed *ad libitum*. Galileo, who had hitherto contented himſelf with the common notion of nature's abhorrence of a vacuum, now acknowledged that this horror had it's limits, and with this he contented himſelf. Galileo had found that the air had weight, but the diſcovery of it's preſſure was reſerved for Torricellius.

When we conſider the abilities of Galileo, and reflect on his various diſcoveries, as of the iſochronical vibrations of the pendulum, the laws of falling bodies, &c. we are ſurprized that he ſhould fail in one apparently more evident, and whoſe boundaries he ſo nearly approached. How great muſt be the force of prejudice, which could have ſuch influence on a mind like that of Galileo!

But mankind had now, for more than a thouſand years, looked up to *Ariſtotle* as an oracle in philoſophy. His authority was the teſt of truth; it was a philoſophy, ſays Lord Bacon, fruitful of words, but barren of works; admirably contrived to draw a veil over ignorance, and put a ſtop to the progreſs of knowledge, by filling men with a conceit that they knew every thing: a philoſophy, that inſtead of accounting for any of the phenomena

mena of nature, contrived to give learned names to their unknown causes, and fed men with husks of barbarous terms, instead of the fruits of real knowledge.* At length men grew wiser by the folly of those that went before them, and a different method of studying nature was invented and pursued; in which fancy was excluded, and fact only allowed for a solid ground of physical progression.

The discovery of the *barometer* by Toricellius in 1643, was one of the first effects of these researches. He formed the first rough model of a barometer in a pipe, or tube of 60, and afterwards of 40 feet in length; which being immerged and suspended in a vessel of water, and the air extracted by a syringe, the water was always found to rise and continue suspended at the height of 32 or 33 feet, with some small variation, but could by no art be drawn, or kept up to the height of 38 or 40 feet.

But this instrument being of an unmanageable length and size, Torricellius considered that the quicksilver endeavours to descend by it's gravity, with a force equal to that by which it's descent is prevented; and comparing the specific gravities of the two fluids, and filling a tube of glass with quicksilver instead of water, he found the effect equally and surprizingly to answer, and by the advantage of so weighty a fluid, he reduced the barometer in it's length from 40 feet to 32 inches; the water being raised as much higher as it was lighter than the mercury. Hence Torricellius concluded, that they were both supported by the same counter-weight, and that this counterpoize was the air; and you will see by other experiments, that when this counterpoize, or the external pressure of the air, is removed, the mercury falls into the bason.

To

* Reid on the Intellectual Powers of the Human Mind, p. 127.

To fill a barometer tube. I take a clean warm glaſs tube about 33 inches long, and pour quickſilver into it by means of a ſmall paper funnel; you obſerve, that as the quickſilver riſes in the tube, there are bubbles of air left behind in ſeveral parts; I continue pouring the quickſilver till it fills the tube within about half an inch of the top. I then apply my finger hard and cloſe upon the top of the tube, and invert it; by which means the air that was on the top, now riſing through all the quickſilver, gathers every bubble in it's way. I revert the tube or turn it up again, and the bubble of air reaſcends, and if there are any ſmall bubbles left, carries them away; if however any remain, the operation muſt be repeated. I now fill the tube to the top, and placing my finger on the open end of the tube, plunge that end into this baſon of quickſilver; when the end of the tube is perfectly ſubmerged in the quickſilver, I take my finger away, and you ſee the quickſilver remains ſuſpended in the tube, leaving a vacuum at top. The column of quickſilver is about 30 inches in height, now you will obſerve that there can be no air in the ſpace between the quickſilver and the top of the tube, for till the finger that cloſed the orifice in the baſon was taken away, that ſpace was filled with quickſilver, and the quickſilver which was 33 inches high, ſunk in the tube, and left that ſpace free from air, for no air could get into the tube, unleſs it could force it's way through the quickſilver in the baſon, and the 30 inches in the tube; or penetrate through the ſealed end of the tube: but as neither of thoſe can be done, it follows, that in the part of the tube which the quickſilver leaves, there muſt be a vacuum.

This experiment was ſoon communicated to the literati of Europe, who led by the bright examples of Galileo and Bacon, were then juſt emerging from

from the darkneſs of the ſchools, and in queſt of new diſcoveries. Among others it had the happineſs of engaging the attention of the deſervedly celebrated *Paſcal*, a man who was as remarkable for unfeigned piety, as for extent of genius. He ſoon rendered evident, what had as yet been conſidered only as probable. His experiments are too numerous to be inſerted here: there is one however which muſt be noticed, not only becauſe it is a ſatisfactory proof, that the preſſure of the air ſupports the mercurial column in the barometer, but alſo becauſe it pointed out a very important uſe of this inſtrument, namely, that of meaſuring the *heights of mountains*. As there is always ſomething to be gained by hearing Paſcal ſpeak for himſelf, I ſhall read to you a letter he wrote in 1647, to Mr. Perrier his brother-in-law. "I have thought," ſays he, "of an experiment, which, if it can be executed with accuracy, will alone be ſufficient to elucidate this ſubject. It is to repeat the torricellian experiment ſeveral times in the ſame day, with the ſame tube and the ſame mercury, ſometimes at the foot, ſometimes at the ſummit of a mountain 5 or 600 fathoms in height. By this means we ſhall aſcertain, whether the mercury in the tube will be at the ſame or a different height at each of theſe ſtations. You perceive without doubt that this experiment is deciſive. For if the column of mercury be lower at the top of the hill, than at the baſe, as I think it will, it clearly follows that the preſſure of the air is the ſole cauſe of the ſuſpenſion of the mercury in the tube, and not the horror of a vacuum; as it is evident there is a longer column of air at the bottom of the hill, than at the top: but it would be abſurd to ſuppoſe, that nature abhors a vacuum more at the baſe, than at the ſummit of a hill. For if the ſuſpenſion of the mercury in the tube is owing to the preſſure of the air, it is plain it muſt be

equal to a column of air, whoſe diameter is the ſame with that of the mercurial column, and whoſe height is equal to that of the atmoſphere, from the ſurface of the mercury in the baſon. Now the baſe remaining the ſame, it is evident the preſſure will be in proportion to the height of the column, and that the higher the column of the air is, the longer will be the column of mercury that will be ſuſtained. M. Perrier tried this experiment on the *Pui de Dome* in the manner preſcribed by M. Paſcal, whoſe conjectures it perfectly verified, for the mercury in the barometer fell in proportion as M. Perrier aſcended the mountain.

Other proofs of the ſame truth are pleaſingly obtained from the air-pump; for by this inſtrument we can ſhew what will happen when the preſſure of the air is removed from the barometer. For this purpoſe I place this barometer on the plate of the pump, putting a long receiver over it. (*fig.* 11, *pl.* 3.) I begin working the pump, and you ſee the mercury immediately deſcends, and that it continues deſcending in the tube, and going into the jar all the while I am exhauſting the air; when there is no air left, there is no mercury ſuſpended. A column of 30 inches was ſuſpended whilſt the air preſſed freely on the mercury; but this height decreaſed as the preſſure grew leſs, and none is ſupported when that preſſure is removed. The preſſure of the air being the power by which the mercury is ſuſtained in the barometer, it is a conſequence that on the removal of the air from the mercury's ſurface, the mercury in the tube muſt deſcend. It is plain that it is the weight of the air that ſupports the mercurial column. This concluſion is confirmed by the readmiſſion of the air into the receiver; for on my doing this, you ſee that the mercury which had before fallen out, is now preſſed into the tube, and riſes therein till it ſtands

 again

again at it's former height. A barometer included in the receiver of an air-pump, is of great uſe in aſcertaining the preſſure of the air remaining in it after having been partly exhauſted. For this preſſure will always be to the preſſure of the atmoſphere on a given ſurface, as the height of the mercury in the tube is to the ſtandard altitude. The barometer when applied to this uſe is called a *guage*. There is another kind of *guage*, (A, *fig.* 2, *pl.* 1,) conſiſting of a ſhort tube hermetically ſealed at one end, filled with quickſilver, and inverted with the open end into a ſmall jar of quickſilver, and placed on a ſmall plate communicating with the receiver. Now as the barometer ſhews the degree of exhauſtion by it's riſing, ſo this guage ſhews how far the air is exhauſted by the deſcent of the quickſilver: for as the air is drawn out of the receiver, it is at the ſame time drawn out of the glaſs placed over the guage, and conſequently it's preſſure on the quickſilver in the baſon being conſtantly diminiſhed, it will at length become leſs than the weight of the mercury in the tube, at which time the mercury will begin to ſubſide; and as the air is further exhauſted, will ſtill ſink lower, till at laſt it will ſtand but a very ſmall height above the ſurface of that in the jar.

I ſhall give you one proof more by an experiment of ſo ſimple a nature, that you may eaſily repeat it; no apparatus is required, but a glaſs tube open at both ends; with this, ſome mercury and a piece of bladder, you may readily prove to any of your companions, the principles on which ſo heavy a fluid as mercury remains ſuſpended in the barometer. Here is a tube of glaſs, about 33 inches long, open at both ends; I ſhall cloſe one of the ends with this piece of wet bladder, tying it faſt thereon. I now fill the tube as I did the barometer, put my finger on the open end,

 and

and immerge the end covered by my finger in this veſſel of mercury without letting in any air; I take away my finger, and you perceive that a part of the mercury precipitates itſelf into the baſon, and the reſt remains ſuſpended as in our former experiments. You obſerve alſo, that the bladder is forced into the tube, being convex on the ſide next the mercury. I ſhall now make a hole in the bladder with a fine needle; you ſee with what velocity the mercury is precipitated into the baſon; the column of air that entered at the top, being equal to that by which the mercury was ſuſpended, the mercury deſcends by it's own weight.

Though theſe experiments render this ſubject ſo plain and evident, yet on it's firſt diſcovery, it had to ſtruggle with the prejudices of thoſe who had been accuſtomed to think only in a certain ſyſtematic way, and who could not be prevailed on to abandon their favourite opinions. The various ſubterfuges employed at this period, and their confutations, may be ſeen in the works of Paſcal, Boyle, and Power. By degrees, however, the experiment you have ſeen ſoftened ancient prejudices, the prepoſſeſſions in favour of an abſurd ſyſtem vaniſhed, and the weak opinion by which the multitude is governed, began to loſe it's influence.

You have ſeen the preſſure of the air downwards; I ſhall now ſhew you the action of this preſſure in different directions, for like other fluids it preſſes equally every way. I have here a tube for the torricellian experiment with a lateral opening covered by a bladder; I fill and invert it, as in the preceding caſes, and you ſee the mercury remains ſuſpended as before; I pierce the bladder, and the air which enters by this aperture, divides the column of mercury into two parts,

forcing

forcing one downwards into the bason, and carrying the other upwards with great violence against the top of the tube; thus shewing you the action of the air in two different directions.

Here is a barometer properly filled, and immersed in a bason of mercury; the bason is so deep, that you may lift the tube up a good way, without raising the lower orifice above the surface of the mercury; you will find that on lifting the tube you raise a weight equal to that of the column of mercury sustained in it. That this is not the weight of the mercury, is evident from this consideration, that in lifting the tube you do not raise the mercury, the tube rises by itself, and slips over the column of mercury contained in it; the top of this column being no further from the surface of the stagnant mercury after you have lifted up the tube, than it was before. Neither indeed ought the weight of the mercury in the tube to be felt; for the pressure of the atmosphere upwards supports that weight. But as the pressure upwards is thus counterpoized by the mercury in the tube, there is nothing to support and counteract the weight of the column of air which presses downwards upon the top of the tube. This pressure will therefore be felt in lifting the tube, and as it is equal to the weight of 30 inches of mercury, lifting this pressure is, as to sense, just the same as lifting the weight of mercury in the tube.

From these experiments it is evident, that the surface of the globe on which we live sustains an ocean of air, that is circumfused about it to a considerable height. The inhabitants on it's surface resemble therefore the fishes at the bottom of the ocean; like them we are surrounded by a fluid that rises far above our heads.

A square column of quicksilver 29 ½ inches high, and 1 inch in diameter, is estimated to weigh

 15 pounds,

15 pounds. Such then at a medium, is the preſſure of the air on every ſquare inch of the earth's ſurface; and as a ſquare foot contains 144 ſquare inches, the preſſure muſt be 144 times as much, or 2160 pounds on every ſquare foot; ſo that a middle ſized man, whoſe ſurface may be eſtimated at 14 ſquare feet, ſuſtains a preſſure of 30240 pounds.

The following is a computation of the weight of all the air which preſſes upon the whole ſurface of the earth. If this weight were to be expreſſed by the number of pounds it contains, that number would be ſo large as to be in a manner incomprehenſible. We ſhall therefore make uſe of another mode of expreſſing it, by determining the diameter of a ſphere of lead of the ſame weight with all the air which preſſes upon the whole ſurface of the earth. That diameter is found to be nearly 60 miles long.* Great as this preſſure is, the removal thereof would prove a cauſe of immediate death. We even as it were enjoy the load, and "it is as wings to our feet, and ſinews to our limbs." Sounds travel through it with great rapidity; odours and emanations of all kinds find no difficulty in moving it forward, and preſſing it aſide.

Though our bodies ſupport a weight of nearly two tons, you need not wonder at the freedom with which you traverſe the atmoſphere, ſince you ſee fiſh move with as great eaſe in a much more denſe and more weighty element. You are not ſenſible of this enormous weight, becauſe you have been accuſtomed to it, and ſupported it from your earlieſt infancy. Senſations to which we have been always and at all times accuſtomed, are ſeldom felt; we can perceive no differences where we can have no ſtandard to judge of variation. Divine Providence has alſo counteracted this preſſure by

* Cote's Hydroſtatical Lecture, p. 94.

by the ſpring of the air which is diffuſed through the whole body. We therefore do not feel the weight of the incumbent atmoſphere; firſt, becauſe it is counteracted, and ſecondly, becauſe it has always acted upon us, and we cannot remove from it's preſſure.

OF THE ELASTICITY OR SPRING OF THE AIR.

Air is elaſtic and compreſſible. It is compreſſible, for the parts may be brought cloſe together, and made to occupy a ſmaller ſpace; but when that force is removed, it expands or ſprings out again, ſo as to occupy the ſame ſpace it did before it was compreſſed. This property diſcriminates air from many other fluids; thus a quantity of water, mercury, &c. of any given magnitude, can never be reduced in it's dimenſions ſo as to occupy a ſmaller portion of ſpace; whereas air will by compreſſion ſuffer a very great diminution of it's bulk. In other words the air conſiſts of, or at leaſt abounds with, parts of ſuch a nature, that in caſe they be compreſſed, and thereby reduced into leſſer dimenſions, either by the weight of the incumbent atmoſphere, or by any other force, they endeavour as much as in them lies to free themſelves from that preſſure, and regain their former dimenſions by bearing againſt the contiguous bodies that keep them in. This propenſity may be illuſtrated by a compariſon. Here is a handful of wool which I preſs cloſe together, and reduce into a ſmall compaſs; I open my hand, and it recovers it's former bulk from the natural ſpring of the fibres. The air is always compreſſed by it's own weight, and the expanſion of the contiguous air: conſequently the air in a valley is more compreſſed than that on the top of a mountain. It may therefore be compared to many fleeces of wool laid one upon the other; it is

is evident that as the lower ſtrata ſupport the weight of the ſuperior ones, they will be more loaded than the upper ones, and will conſequently be flattened, and have leſs bulk with the ſame maſs, and therefore be more denſe or compact. The denſity of the next upwards will be leſs, becauſe it will ſupport leſs weight, and ſo of the remainder. It is thus alſo with air.

To ſhew you that the air is elaſtic, I have no occaſion for any inſtrument, as it will be ſufficiently proved by your only preſſing this bladder between your hands. You find that the force you exert, reduces the air contained in the bladder into a leſs ſpace, but that as ſoon as you ceaſe to preſs, it immediately expands and fills the ſame ſpace as before. You may even perceive, while you compreſs it, a very great endeavour to free itſelf from the violence you offer to it.

The elaſticity of the air, the ſecond great ſource of the effects of this important fluid, was firſt aſcertained by ſome experiments of Lord Bacon, the friend and father of modern philoſophy, who upon this principle conſtructed his firſt thermometer, which he called his *vitrum calendare*.

In conſequence of this elaſtic principle, the air always endeavours to expand itſelf, and occupy more ſpace. Here is a bladder containing only a ſmall quantity of air, the neck is tied cloſe to prevent the air from eſcaping; ſo long as this bladder is expoſed to the common preſſure of the atmoſphere, it will remain in the ſame ſtate, the external and internal air being of the ſame denſity; but when I put it under this receiver, and begin to rarify the external air by working the pump, the ſide of the bladder, which before was flabby and lax, ſtretches itſelf out and becomes tight, being raiſed up by the elaſtic power of the air within it, (*fig.* 10, *pl.* 1.) When I let in the ex-

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ternal air, the bladder returns to it's former ſhape, the external air preſſing down the bladder till the internal air is reduced to a denſity capable of counteracting and ſupporting the whole weight of the atmoſphere.

Though only a ſmall quantity of air was contained in the bladder deſigned for the preceding experiment, yet that ſmall quantity is capable of raiſing a conſiderable weight. I put it in this box, cover it with theſe leaden weights, place it on the plate of the pump with a receiver over it. (*fig.* 6, *pl.* 2.) In proportion as I exhauſt the air, the bladder ſwells, raiſing the incumbent weight; on the readmiſſion of the air, the weights ſubſide to their former ſituation. As you have ſeen ſo ſmall a quantity of air lift ſo conſiderable a weight, you will be leſs ſurprized when I inform you, that by blowing into a bladder very large weights may be raiſed. Sturmius connected ſeveral bladders with a pipe in ſuch a manner, that there was a free communication from the pipe to all the bladders; he then placed a mill-ſtone on the bladders, and was able to raiſe it ſenſibly by blowing ſtrongly with the mouth into the pipe.

Here is a thin bottle with flat ſides, there is a cork in the neck, and the cork is covered over with cement to prevent the air within the glaſs from eſcaping; I ſhall place it under a receiver, putting this cage previouſly over it. I work the pump, and as ſoon as the air is ſufficiently rarified, the ſpring of the air within will dilate with ſo much force as to break the bottle. This experiment has given riſe to a problem, in which the form of a phial is required capable of ſo reſiſting the force of the included air, as not to break when the external preſſure was taken off. This form was determined to be a ſphere, in which with the ſame maſs, you have the greateſt bulk under

under the leaſt ſurface; conſequently, a bottle of this form will be the ſtrongeſt that can be made out of the ſame maſs or quantity of materials.

I place this ſhrivelled apple under a receiver, and exhauſt the air therefrom; the ſkin ſwells as ſoon as I begin to work the pump, the wrinkles fill up, and the apple now appears as one freſh gathered. I let in the air, and it returns to it's withered ſtate.

In the doubling of the film at the large end of an egg, there is incloſed a ſmall quantity of air; this air being dilated by the warmth of the hen, preſſes on the contents of the egg, and contributes to the formation and production of the chicken. This included air will afford us a very pleaſing experiment, illuſtrative of it's expanſive force. Let us break off about one third part of the ſhell at the ſmall end of the egg, invert it, throw away the contents, then place it under a receiver, and exhauſt the air therefrom. You ſee that the air which is between the ſhell and the ſkin dilates, and ſwells the ſkin ſo much beyond the broken part, that the egg appears as if it were whole. You may vary this experiment by making a little hole at the ſmall end of an egg, then place it in this apparatus with the ſmall end downwards, and put the whole under a receiver with a ſmall jar to receive the contents of the egg. On working the pump, the air within will dilate, ſo as to force the white and yolk out through the hole in the egg. If the jar be conical, and the egg be let down gradually, the white and yolk will be forced up again on the readmiſſion of air; or if theſe be thrown away, and water be ſubſtituted in their place, the inſide of the egg may be waſhed, and afterwards in the ſame manner filled with cream or any other fluid.

The

The next experiment will ſhew you how naturally the air will force itſelf out by it's ſpring, from any veſſel in which it is contained, when the preſſure of the external air is taken away. This phial with a long neck is commonly called *a bolt-head.* I put the neck into a tumbler of water, and both under a receiver on the pump, (*fig.* 18, *pl.* 1.) By diminiſhing the maſs of air within the receiver, I weaken proportionably the ſpring thereof, and conſequently it's preſſure upon the air within the bolt-head; this diſcharged of a part of it's weight, dilates and eſcapes from the bottle in the form of bubbles, which being lighter than water aſcend through it, and burſt upon it's ſurface: this will laſt till the power of expanſion is too weak to overcome the incumbent preſſure. Let us now ſee what will be the conſequence of readmitting the air into the pump, the external air being more denſe than that in the bottle, and yielding to this exceſs of preſſure, the water will enter the orifice, and meeting with little or no reſiſtance, will mount therein till the remaining maſs of air is reduced to the ſame denſity with the external air. The little bubble at the top of the bolt-head, is what remained after the exhauſtion, and is now condenſed into a ſmall ſpace. You ſee how ſmall a quantity of air remains when compared to the whole at firſt contained in the globe, or to the bulk of water now in it, which is equal to the quantity of air extracted. You may perceive by this experiment, that the ſpring of the air is equal to the weight, as it produces an equal effect; for while the ſpring of the air was leſs than the weight of the external air, the water kept riſing in the globe; but when the ſpring became equal to the external preſſure, the water was ſubject to both their influence, and finding it equal on either ſide, could no longer move.

Now

Now let us again exhauſt the air from the receiver; I have no ſooner moved the handle than the water begins to deſcend, the bubble of air expands, and forces the water gradually out of the bottle.

By this time you may ſee, that unleſs the air was *elaſtic*, it could not be exhauſted out of a cloſe veſſel. If the veſſel was filled with water, and there was no orifice but where the pump was ſcrewed on, though a vacuum be made by drawing up the piſton, yet no water would riſe out of the veſſel into that vacuum; for the water is raiſed into a vacuum by the preſſure of the atmoſphere upon the other parts of the ſurface. But as the veſſel is cloſe, the external air cannot preſs upon it's ſurface, and no water will riſe into the vacuum, and none can be pumped out unleſs it firſt riſes in the barrel. But if the veſſel be filled with an elaſtic fluid, it does not want an external preſſure to raiſe it, but will expand itſelf by it's own elaſticity, ſo that the ſame air, which firſt filled the veſſel, will after it is thus expanded fill both the veſſel and the ſpace in the barrel too. And whatever part of the air riſes into the barrel of the pump upon the drawing up of the piſton, will be carried off by it's next return.

Fountains may be made to play on various plans. I have already ſhewn you one by the preſſure of the air; our next experiment will be on one ſet in action by the ſpring of the air. This bottle is about 2 thirds filled with water, the upper part is occupied by the air, the top of the glaſs tube is furniſhed with a ſcrew and jet, the glaſs tube paſſes through the neck of the bottle, and reaches nearly the bottom, and is fixed there by the ſcrew on the upper part, which ſcrews into the top of the bottle ſo as to render it air-tight, (*fig.* 8, *pl.* 2.) Place this on the pump under a receiver, and after a few

ſtrokes

ſtrokes which have leſſened the external preſſure, you will give the air within an opportunity to expand, and thereby to force the water out through the glaſs tube; which it does with ſo much force, as to form a very pleaſing jet d'eau.

Here is a ſmall *Bacchus (fig. 2, pl. 2,)* ſeated on a caſk with a tube proceeding from his mouth to the barrel; this is filled with coloured water in the ſame manner as the ſmall fountain, ſo that on being put under a receiver when the air is exhauſted, the liquor is thrown up into his mouth, and the roſy god ſeems to be at his uſual employment; while he is drinking his belly expands, which is effected by a bladder, containing a ſmall quantity of air concealed under his ſhirt.

The elaſticity or ſpring of the air produces the ſame effects that the preſſure produces, *becauſe the ſpring is equal to the compreſſing force*, which in ordinary caſes is equivalent to the preſſure of the air. This barometer tube is open at both ends, I ſhall ſcrew the braſs collar of the tube into the neck of this bottle; you ſee that the lower end of the tube is beneath the ſurface of the quickſilver in the bottle, and that the air above the quickſilver cannot poſſibly eſcape, for it cannot get through the quickſilver into the tube, nor paſs through the joinings at the top of the phial which are made air-tight. I place this apparatus on the pump, putting a receiver over it; at preſent the mercury is in a ſtate of tranquillity, as nothing acts upon it to occaſion an alteration in it's ſituation. I exhauſt the air from the receiver and tube, and you ſee that the ſpring of the air contained in the bottle preſſes upon the mercury, and will force it up nearly as high as it was raiſed by the preſſure of the air in the former experiment; for as ſoon as the counter-weight was taken off by exhauſtion, the ſpring exerted it's power.

Before

Before you is a jar filled with water, in which are a few hollow glaſs images with a glaſs ball over their heads; this ball contains at preſent juſt ſo much water as to render the images ſpecifically heavier than water. I ſhall place them on the pump, under a receiver, (*fig.* 13, *pl.* 2,) and exhauſt the air, and you ſee that in proportion as this is rarified the images riſe, the air included in the ball dilates, and forces out a part of the water, and the figure and it's balloon, now becoming lighter than the water, aſcends; on letting in the air, the whole becomes ſpecifically heavier again, and deſcends to the bottom.

In the foregoing experiment it was evident, that the ſpecific weight of the bodies was diminiſhed by the expanſion of the air: as this fact explains ſome common phenomena, and is applicable to a variety of circumſtances, I ſhall endeavour to render it more familiar to your minds by one or two experiments. This bladder, containing only a ſmall quantity of air, has a piece of lead affixed to it of ſufficient weight to ſink the whole in the water. I put it in this jar of water, and place them on the pump, under a receiver; I exhauſt the air, the bladder expands, becomes a balloon lighter than the fluid in which it floats, and aſcends carrying the weight with it. This experiment will naturally call to your minds the air-balloons, which you have ſeen or heard of: you ſaw one in the preſent inſtance aſcend in water, as ſoon as it's bulk was rendered lighter than the ſame bulk of water; in the other caſe, the air-balloons are rendered lighter than the air in which they float, and conſequently aſcend till an equilibrium takes place. But theſe will make the ſubject of a future lecture.

I have affixed juſt ſuch a weight of lead to this piece of cork, as will make it ſink in water. I put

it

it into the jar of water, and place the whole under a receiver on the pump, and exhauſt the air therefrom; you ſee the air diſengaging itſelf from the cork, riſing up in the form of little bubbles which burſt on the ſurface of the water; but a part of the air cannot eſcape, the cork therefore increaſes in bulk, becomes ſpecifically lighter than the water, and aſcends therein; on readmitting the air, it ſhrinks to it's former bulk, and deſcends to the bottom of the jar.

Timber dug out of bogs and other moiſt places, will ſeldom float in water, the particles of water having through time and other cauſes diſlodged the air from the vacuities of the wood; hence alſo it appears, that even wood is no otherwiſe comparatively lighter than water, than from the quantity of pores therein filled with air. On the ſame principle we account for the following appearances. If a man or any animal falls into the water, and is drowned, the carcaſe in a few days riſes and floats on the ſurface. The privation of life, the ſtagnation of the fluids, &c. is ſoon followed by a putrid fermentation, deſtroying and decompoſing the body. This fermentation diſengages a great quantity of air, that is diſſeminated among the fluid molecules, and as this air cannot eſcape, the body ſwells till it becomes ſpecifically lighter than the water, and riſes to it's ſurface, and ſwims thereon. The putrefaction going on, the parts give way, the air eſcapes, and the body ſinks. It often however happens, that in the progreſs of diſſolution, freſh air is generated, and the body riſes and ſinks alternately according to theſe changes.

The *preſſure* of the air is the firſt great ſource of it's effects; it's *elaſticity* is the ſecond; by this, when it has inſinuated itſelf into the pores of bodies, it keeps their particles in continual oſcillation; for the degree of heat, the gravity and denſity of

of the air, and consequently it's expansion and elasticity, never remaining the same for the least moment of time, there must be an incessant contraction and dilatation in all bodies.

This reciprocation may be observed in several instances, particularly in plants; for the contained air alternately expanding and contracting according to the increase or diminution of heat, alternately presses the vessels, and eases them again, thus keeping up a perpetual motion in their juices.

From the same cause the air contained in the bubbles of ice, by it's continual action bursts the ice; and for the same reason it acts as a principal cause in the phenomena of fermentation and putrefaction.

In a clear sun-shiny day, you may often perceive all the objects of nature as if trembling before your eyes; this is usually ascribed to the rising of vapours; but a little observation will soon prove to you, that it is owing to the alternate expansion and contraction of the air.

Air seems to act on the smooth surface of the leaves, or the bark of the stem of plants. If there be not a continual supply of fresh air, the stem runs out to a great length, is exceedingly small and weak, the leaves endeavour to spread out to a great distance, no impregnation takes place in the flowers, the proper juices are not formed, and the whole plant is destroyed.

Many conjectures have been offered, and hypotheses framed, to account for the elasticity of the air. Some have compared the air to watch-springs or hoops, which coiled up by pressure restore themselves again as soon as the pressure is removed: others have resembled them to flocks of wool: notions that are inadequate to the solution of the phenomenon, and probably without foundation. These suppositions seem to shew an inattention to the subject

ject of inquiry, as the property of elaſticity ſeems rather to lie in the peculiarity of the matter than in the form. A piece of lead rolled up like a watch-ſpring, will acquire thereby no elaſtic power. It is probable, that this property is owing to ſomething elſe beſides the form or the ſhape of the particles. Others have attributed the elaſticity of the air to a repulſive power in the particles. This ſolution does not ſeem in the leaſt to remove the difficulty; it is ſaying no more, though in other words, than that the particles ſeparate; the ſeparation or repulſion is the fact, the cauſe is to be explored for the fact; that is, the expanſive or ſeparating force is allowed by all.

You were aſtoniſhed at the amazing elaſticity fire gives to water, when you ſaw the ſteam engine erected by Meſſrs. Watts and Bolton, at Mr. Whitbread's brewery; the ſteam of boiling water is as elaſtic as air. The force of this ſteam may be increaſed to almoſt any degree in Papin's digeſter, the power is incredible, and without proper care would burſt the ſtrongeſt veſſel; it is evidently fire that renders ſteam elaſtic. There is no improbability, therefore, in ſuppoſing that it occaſions alſo the elaſticity of air. Perhaps we ſhall not be far diſtant from the truth, if we ſay with *Boerhaave*, that the active force in the air, which produces ſo many effects, *does all ariſe from the fire contained in it*.

Not to truſt to conjecture, let us have recourſe to experiment. I take this bladder half filled with air and tied cloſely about the neck; I hold it near the fire, and it immediately ſwells; the nearer I approach, and the longer I hold it there, the more the bladder expands; the elaſticity of the included air increaſing as the action of the fire increaſes. As a great degree of fire gives more elaſticity, and a ſmall degree leſs elaſticity to

the ſame quantity of air, *this element* ſeems to have the direction of this quality, and to be the phyſical cauſe of it at all ſeaſons. That fire is the power by which the air is kept in continual motion, is alſo evident from the thermometer of Drebellius.

One objection however has been made to this theory, which ſhould be obviated; the bladder will diſtend when a part of the ſurrounding air is withdrawn, in the ſame manner as if it were held before the fire. If fire be the immediate cauſe of the repulſion, it has been aſked, Why does the repulſion increaſe, when the heat remains the ſame? The anſwer is plain and eaſy; there is the ſame heat in the receiver as in the circumambient air; this heat is ſufficient for the purpoſe, and muſt neceſſarily produce the effect when the preſſure of the air is taken off.

As long as the receiver is full of air in the ſame ſtate with that in the bladder, there are two equal forces counteracting one another; there is the air in the bladder rendered elaſtic by the ſtanding degree of heat at that time in the atmoſphere, and there is air equally elaſtic preſſing with equal force on the outer ſurface of the bladder; ſo that while things remain in this ſtate, all will be at reſt. But the effect will be the ſame, whether you *add more heat* to the inſide, or *take away an equivalent degree of reſiſtance* from the outſide; a rarifaction muſt follow upon either of theſe changes, for to ſubtract the reſiſtance from the outſide of the bladder, is the ſame as to add a greater force of expanding fire within ſide. Many experiments in the courſe of this work will be found to ſtrengthen this opinion; and it does not appear that there is a ſingle experiment to prove any elaſticity in the air independent of fire.

The

The elastic power of the air is always equivalent to the force which compresses it, for if it were less, it is clear it would yield and be more compressed; were it greater, it would not be so much reduced; for action and re-action are always equal. So that the elastic force of any small portion of the air we breathe, is equivalent to the weight of the incumbent part of the atmosphere; that weight being the force which confines it to the dimensions it possesses. Hence the air is always a counterballance to itself, and naturally in equilibrio like other fluids. Air compressed by twice the weight of the atmosphere, is reduced to half the space it before occupied, by four times that weight to one quarter of the space, and so on in a geometrical progression, supposing the heat to be always the same.

To illustrate these laws relating to the air's elasticity, we shall take this bent tube, whose smaller leg is hermetically sealed; (*fig.* 1, *pl.* 4;) holding it with the curvature downwards, I pour a small quantity of quicksilver into the tube, so as just to fill the horizontal part, in order to confine the air contained in the smaller leg. Now it must be evident to you, that in this case, the air in the smaller leg cannot be pressed by any other weight than the common pressure of the atmosphere. I shall now pour more quicksilver into the longer leg, which will compress the air in the shorter one, and confine it to a smaller space. By pouring additional quicksilver into the longer leg, you will find that the space into which the shorter one is reduced, is to the space it occupied with the atmospheric pressure, as the atmospheric pressure to the same pressure with the weight of the additional quicksilver. In other words, by increasing the quantity of quicksilver the condensation is increased, and it is found *that the*

ſpace into which the air is condenſed by different weights is inverſely as thoſe weights; or it's denſity is as the preſſure it bears. When we ſay that it is inverſely as the compreſſing force, we mean that the ſpace is diminiſhed in the ſame proportion in which the force is increaſed; and thus a double force reduces the air into half the ſpace, a triple force reduces it into a third part of the ſpace it poſſeſſed before; ſo half the force permits the air to expand itſelf into double the ſpace, and a third part of the force permits it to expand into a ſpace triple of what it poſſeſſed before.

After what has been ſaid, it ſeems almoſt needleſs to obſerve to you, that the more the air is compreſſed, the denſer and heavier it becomes: it being evident that a given quantity of air confined in half the ſpace it naturally occupies, muſt become twice as denſe, twice as heavy as it was before, and muſt offer a greater reſiſtance to the motion of the bodies.

OF THE HEIGHT OF THE ATMOSPHERE.

Having proved to you, that the ſpring or elaſtic power of the air is as the force which compreſſes it, and that the denſity is as the ſaid force, the ſpace it poſſeſſes being always reciprocal to that force; we are furniſhed with ſome data to make inquiry concerning the limits of the atmoſphere, and it's ſtate as to rarity at different elevations from the earth's ſurface; ſubjects that have engaged the attention of mathematicians ever ſince the diſcovery of atmoſpheric preſſure; *they* love to purſue a ſubject when calculation is all that is neceſſary; calculations may ſometimes give information, they ſeldom confer wiſdom.

Theſe attempts commenced ſoon after it was diſcovered, by means of the torricellian tube, that air is a gravitating ſubſtance. Thus it alſo became known that a column of air, whoſe baſe

is a ſquare inch, and the height that of the whole atmoſphere, weighs 15 pounds; and that the weight of air is to that of mercury, as 1 to 10,800: whence it follows, that if the weight of the atmoſphere be ſufficient to raiſe a column of mercury to the height of 30 inches, the height of the aerial column muſt be 10,800 times as much, and conſequently a little more than five miles high.

It was not, however, at any time ſuppoſed, that this calculation could be juſt; for as the air is an elaſtic fluid, the upper parts muſt expand to an immenſe bulk, and thus render the calculation above related exceedingly erroneous. By experiments made in different countries, it has been found, that the ſpaces which any portion of air takes up, are reciprocally proportional to the weight with which it is compreſſed. Allowances were therefore to be made in calculating the height of the atmoſphere. If we ſuppoſe the height of the whole divided into innumerable equal parts, the denſity of each of which is as it's quantity; and the weight of the whole incumbent atmoſphere being alſo as it's quantity; it is evident, that the weight of the incumbent air is every where as the quantity contained in the ſubjacent part; which makes a difference between the weights of each two contiguous parts of air. By a theorem in geometry, where the differences of magnitudes are geometrically proportional to the magnitudes themſelves, it appears that theſe magnitudes are in continual arithmetical proportion; therefore, if, according to the ſuppoſition, the altitudes of the air, by the addition of new parts into which it is divided, do continually increaſe in arithmetical proportion, it's denſity will be diminiſhed, or (which is the ſame thing) it's gravity decreaſed in continual geometrical proportion.

It is now eaſy, from ſuch a ſeries, by making two or three barometrical obſervations, and determining the denſity of the atmoſphere at two or three different ſtations, to determine it's abſolute height, or it's rarity at any aſſignable height. Calculations accordingly were made upon this plan; but it having been found that the barometrical obſervations by no means correſponded with the denſity which, by other experiments, the air ought to have had, it was ſuſpected that the upper parts of the atmoſpherical regions were not ſubject to the ſame laws with the lower ones. Philoſophers therefore had recourſe to another method for determining the altitude of the atmoſphere, viz. by a calculation of the height from which the light of the ſun is refracted, ſo as to become viſible to us before he himſelf is ſeen in the heavens. By this method it was determined, that at the height of 45 miles the atmoſphere had no power of refraction; and conſequently beyond that diſtance was either a mere vacuum, or the next thing to it, and not to be regarded.

This theory ſoon became very generally received, and the height of the atmoſphere was ſpoken of as familiarly as the height of a mountain, and reckoned to be as well aſcertained, if not more ſo, than the heights of moſt mountains are. Very great objections, however, which have never yet been removed, ariſe from the appearances of ſome meteors, like large globes of fire, not unfrequently to be ſeen at vaſt heights above the earth. A very remarkable one of this kind was obſerved by Dr. *Halley* in the month of March 1719, whoſe altitude he computed to have been between 69 and 73½ Engliſh miles; it's diameter 2800 yards, or upwards of a mile and a half; and it's velocity about 350 miles in a minute. Others apparently of the ſame kind, but whoſe altitude and velocity

velocity were ſtill greater, have been obſerved: particularly that very remarkable one, Auguſt 18th 1783, whoſe diſtance from the earth could not be leſs than 90 miles, and it's diameter not leſs than the former; at the ſame time, that it's velocity was certainly not leſs than 1000 miles in a minute Fire-balls, in appearance ſimilar to theſe, tho' vaſtl. inferior in ſize, have been ſometimes obſerved at the ſurface of the earth. Of this kind, one was ſeen on board the Montague, 4th November 1749, which appeared as big as a large mill-ſtone; it broke with a violent exploſion.

From analogical reaſoning, it ſeems very probable that the meteors which appear at ſuch great heights in the air, are not eſſentially different from thoſe which, like the fire-ball juſt mentioned, are met with on the ſurface of the earth. The perplexing circumſtances with regard to the former are, that at the great heights above-mentioned, the atmoſphere *ought not to have any denſity ſufficient to ſupport flame, or to propagate ſound*; yet theſe meteors are commonly ſucceeded by one or more exploſions, nay are ſometimes ſaid to be accompanied with a hiſſing noiſe as they paſs over our heads. The meteor of 1719 was not only very bright, inſomuch that for a ſhort ſpace it turned night into day, but was attended with an exploſion, heard over all the iſland of Britain, occaſioning a violent concuſſion in the atmoſphere, and ſeeming to ſhake the earth itſelf. That of 1783 alſo, though much higher than the former, was ſucceeded by exploſions; and, according to the teſtimony of ſeveral people, a hiſſing noiſe was heard as it paſſed. Dr. Halley acknowledged, that he was unable to reconcile theſe circumſtances with the received theory of the height of the atmoſphere; as, in the regions in which this meteor moved, the air ought to have been 300,000 times

more rare than what we breathe, and the next thing to a perfect vacuum.

In the meteor of 1783, the difficulty is ſtill greater, as it appears to have been 20 miles farther up in the air. Dr. Halley offers a conjecture, indeed, that the vaſt magnitude of ſuch bodies might compenſate for the thinneſs of the medium in which they moved; whether or not this was the caſe, cannot indeed be aſcertained, as we have ſo few data to go upon; but the greateſt difficulty is to account for the brightneſs of the light. Appearances of this kind are indeed with great probability attributed to electricity, but the difficulty is not thus removed; though the electrical fire pervades with great eaſe the vacuum of a common air-pump, yet it does not in that caſe appear in bright well defined ſparks as in the open air, but rather in long ſtreams reſembling the aurora borealis. From ſome late experiments indeed, Mr. Morgan concludes that the electrical fluid cannot penetrate a perfect vacuum. If this be the caſe, it ſhews that the regions we ſpeak of are not ſuch a perfect vacuum as can be artificially made; but whether they are or not, the extreme brightneſs of the light ſhews that a fluid was preſent in thoſe regions, capable of confining and condenſing the electric matter as much as the air does at the ſurface of the ground; for the brightneſs of theſe meteors, conſidering their diſtance, cannot be ſuppoſed inferior to that of the brighteſt flaſhes of lightning.

It appears therefore, that the abſolute height of the atmoſphere is not yet determined. The beginning and ending of twilight indeed ſhew, that the height at which the atmoſphere begins to refract the ſun's light, is about 44 or 45 Engliſh miles. But this may, not improbably, be only the height to which the aqueous vapours are carried;

for

for it cannot be thought any unreaſonable ſuppoſition, that light is refracted only by means of the aqueous vapour contained in the atmoſphere: and where this ceaſes, it is ſtill capable of ſupporting the electric fire at leaſt as bright and ſtrong as at the ſurface. That it does extend much higher, is evident from the meteors already mentioned: for all theſe are undoubtedly carried along with the atmoſphere; otherwiſe that of 1783, which was ſeen for about a minute, muſt have been left 1000 miles to the weſtward, by the earth flying out below it in it's annual courſe round the ſun.

I cannot leave this ſubject without laying before you the following thoughts of Dr. *Horſley*, *Biſhop of St. David's*. That they are his, is ſufficient to entitle them to attention, and you will find yourſelves highly rewarded by the maſculine and energetic ſtile, which ſo peculiarly characterize our worthy biſhop. "I know not," ſays he, "for what reaſon mathematicians have been afraid to admit the infinitude of the atmoſphere of the earth; whether they thought it would bear hard upon the Newtonian doctrine of a void, or that it implied the infinitude of matter. But neither the one nor the other of theſe conſequences is to be apprehended; for neither the phenomena of nature, nor the principles of the Newtonian philoſophy, require that there ſhould be any where a great chaſm in the univerſe, or that the whole material world ſhould be actually circumſcribed by any finite ſpace. A large portion of pore or interſperſed vacuity is ſufficient for all purpoſes. Nor does an abſolute infinity of matter follow from the hypotheſis of an infinite number of finite maſſes, and an infinite number of finite maſſes is all that is implied in the notion of a rare elaſtic fluid, diffuſed through infinite ſpace. There are indeed no data from which any great altitudes of the atmoſphere can

can be indubitably concluded in the way of experiment; but I do contend, that there are no data, from which the ſuppoſition of it's infinite height can, in the ſame way, be diſproved; and this may juſtly be held more probable than the contrary, as being the conſequence of a theory, which has never yet in any inſtance proved fallacious."

"If the atmoſphere of the earth reaches to infinite heights with a finite denſity; thoſe of Jupiter, and every other planet, will reach alſo to infinite heights above the ſurface of the planet with a finite denſity. The atmoſphere of every planet will therefore reach to the ſurface of every other planet, and to the ſurface of the ſun, and the atmoſphere of the ſun to the ſurfaces of them all. All theſe atmoſpheres will mingle, and form a common atmoſphere of the whole ſyſtem. This common atmoſphere of the ſyſtem will be infinitely diffuſed, ſince the particular atmoſpheres that compoſe it are ſo. It will reach therefore to every fixed ſtar; and for the ſame reaſon that of every fixed ſtar will reach the central body of our ſyſtem, and of every other ſyſtem; the atmoſphere of all the ſyſtems will mix; the univerſe will have one common atmoſphere, a ſubtle elaſtic fluid which pervades infinite ſpace; and being condenſed near the ſurface of every larger maſs of matter, by the gravitation towards that maſs, forms it's peculiar atmoſphere."

ON HYPOTHESES.

In the hiſtorical part of the preceding lecture, there are ſome facts, which if properly attended to, will be of great uſe to you. You have ſeen how long bare conjecture was ſuffered to ſtand in the place of knowledge, and with what tenacioufneſs it was adhered to. Conjecture may lead you

you to form opinions, but it cannot produce knowledge. Natural philoſophy muſt be built upon the phenomena of nature diſcovered by obſervation and experiment.

Conjectures in philoſophy are termed hypotheſes or theories; and the invention of an hypotheſis founded on ſome ſlight probability, which accounts for many appearances in nature, has too often been conſidered as the higheſt attainment of a philoſopher. If the hopotheſis hangs well together, is embelliſhed with a lively imagination, and ſerves to account for common appearances; it is conſidered by many, as having all the qualities that ſhould recommend it to our belief, and all that ought to be required in a philoſophical ſyſtem.

Men of genius are ſo prone to invent hypotheſes, and others to acquieſce in them as the utmoſt the human faculties can attain unto in philoſophy, that it is of the greateſt conſequence to the progreſs of real knowledge, that you ſhould have a clear and diſtinct underſtanding of the nature of hypotheſes in philoſophy, and of the regard that is due to them.

Although ſome conjectures may have a conſiderable degree of probability, it is evidently in the nature of conjecture to be uncertain. In every caſe, the aſſent ought to be proportioned to the evidence; for to believe firmly, what has but a ſmall degree of probability, is a manifeſt abuſe of our underſtanding. Now though we may, in many caſes, form very probable conjectures concerning the works of men, every conjecture we can form with regard to the works of God, has as little probability as the conjectures of a child with regard to the works of a man.

The wiſdom of God exceeds that of the wiſeſt man, more than his wiſdom exceeds that of

a child.

a child. If the child were to conjecture, how an army is to be formed in the day of battle, how a city is to be fortified, or a ſtate governed; what chance has he to gueſs right? The wiſeſt man has as little chance when he pretends to conjecture how the planets move in their courſe, how the ſea ebbs and flows, and how our minds act upon our bodies.

If a thouſand of the greateſt wits that ever the world produced, were, without any previous knowledge of anatomy, to ſit down and contrive how, and by what internal organs the various functions of the human body are carried on; how the blood is made to circulate, and the limbs to move; they would not in a thouſand years hit upon any thing like the truth.

Of all the diſcoveries that have been made concerning the inward ſtructure of the human body, never one was made by conjecture. Accurate obſervations of anatomiſts have brought to light innumerable artifices in the contrivance of this wonderful machine, which we cannot but admire as excellently well adapted to their ſeveral purpoſes. But the moſt ſagacious phyſiologiſt never dreamed of them till they were diſcovered. On the other hand, innumerable conjectures formed in different ages with regard to the ſtructure of the body, have been confuted by obſervation, and none ever confirmed.

What we have ſaid of the internal ſtructure of the human body, may be ſaid with juſtice of every other part of the work of God, wherein any real diſcovery has been made; ſuch diſcoveries have been always made by patient obſervation, by accurate experiments, or by concluſions drawn by ſtrict reaſoning from obſervation and experiments, and ſuch experiments have always tended to refute, but not to confirm the theories which ingenious men had invented. If we look back into the

the ſtate of philoſophy, in the different ages, we ſhall learn from the hiſtory of every period, that as far as philoſophers conſulted nature and proceeded on obſervation, they made ſome progreſs in truth, but as far as they pretended to carry on their ſchemes without it, they only multiplied diſputes.

The fineſt productions of human art are immenſely ſhort of the meaneſt works of nature. The niceſt artiſt cannot make a feather or the leaf of a tree: human workmanſhip will never bear a compariſon with the divine. Conjectures and hypotheſes are the inventions and the works of men, and muſt bear proportion to the capacity and ſkill of the inventor, and will therefore be always very unlike to the works of God, which it is the buſineſs of philoſophy to diſcover.

The firſt rule of philoſophiſing laid down by the great Newton, is this, No more cauſes, nor any other cauſes of natural effects, ought to be admitted, but ſuch as are both true and are ſufficient for explaining their appearances. This is a golden rule, it is the true and proper teſt by which what is ſound and ſolid in philoſophy is to be diſtinguiſhed from what is hollow and vain.

If, therefore, a philoſopher pretends to ſhew you the cauſe of any natural effect, whether relating to matter or to mind; you are firſt to conſider whether there be ſufficient evidence that the cauſe he aſſigns, does really exiſt. If there is not, reject it with diſdain as a fiction which ought to have no place in genuine philoſophy. If the cauſe aſſigned really exiſts, conſider in the next place, whether the effect it is brought to explain, neceſſarily follow from it. Unleſs it has theſe two conditions, it is good for nothing.

By obſerving this rule, you will not be in danger of employing mere conjecture, nor ſatisfying yourſelves with the illuſive dreams of imagination, inſtead

inſtead of the real ſtate of things. You have ſeen alſo in theſe lectures the force of prejudice on the mind. Had Bacon, Galileo, Torricellius, or Boyle, given way to the objections thrown in their way, or contented themſelves with the conjectures of their anceſtors, we ſhould have never reaped the benefit of their diſcoveries; diſcoveries that do honour to human nature, and will make their names immortal.*

Truth in it's omniſcient fountain is *univerſal*, *immediate*, *equal*, and *infallible*. The ray with which man is bleſſed, is, from the inferiority and infirmity of his nature, *partial*, *progreſſive*, *various*, though *immutable*: this ray is obſtructed by paſſions, prejudices, habits and vices, cauſes of *error*. Truth, though deſtined to be the guide of man, is not beſtowed with an unconditional profuſion; but is *hidden* in darkneſs, and involved in difficulties; intended, like all the other gifts of heaven, to be ſought and cultivated by all the different powers and exertions of human *reaſon*.†

Let the maxim of the once celebrated Thomas Aquinas be often before you, *cave ab illo qui unicum librum legit*; ſuſpect the knowledge of thoſe who dare not venture abroad in queſt of truth, but under the authority of ſome great name: ſuch, however, is human weakneſs, that you will often find thoſe who will condemn this practice as abſurd, when applied to the prejudices that once reigned in favour of Ariſtotle or Deſcartes, offended when it is brought home to themſelves, and when it is ſhewn that even in this age, authority has undue weight and influence. I hope, that you will be dazzled by no authority, nor ſuffer any popular prejudice to miſlead you, but that you will always be governed and guided by the importance of the matter, the perſpicuity of the facts, the juſtneſs of the inferences, and the ſtrength of the arguments propoſed to you.

* Reid on the Intellectual and Active Powers of the Mind.

† Tatham's Chart and Scale of Truth.

The lowest kind of evidence that can be cited in favour of any doctrine or tenet, is the opinion of great and celebrated men. This evidence is of small authority, because the prejudices of different men, concerning things and persons, of whose merit they are incompetent to judge, is very different. But whatever authority the tenets of any philosopher, or set of philosophers, have, or ever had in the minds of other men; they derive that authority only from a supposed agreement with truth, reason, and nature.

LECTURE III.

IN the preceding lectures, I proved to you that the subtle and invisible element of air is by no means exempted from the universal law of gravitation, and that it's weight is the cause of many phenomena. I have from this principle clearly and naturally accounted for several appearances that could not be explained upon any other. I have shewn to you the nature of that useful instrument the air-pump, and the principles of the celebrated experiment of Torricellius. You have seen that the air is endued with a considerable elastic power, by which it perpetually endeavours to expand itself into larger dimensions, and to remove the obstacles by which it is confined within certain bounds, and that it exerts this power more forcibly as it is more closely crowded together, the force it employs to gain it's liberty being always proportionable to it's coarctation or density. From what you have already seen and heard, you begin no doubt to perceive the nature and design of natural philosophy, that it is intended to describe the principal pheno-

mena of nature, to explain their cauſes, and trace out the relation of the phenomena to, and their dependence on thoſe cauſes. But it is ſubſervient to purpoſes of an higher kind, and will lead you to a knowledge of the author and governor of the univerſe, proving to you the beauty, goodneſs, and equity of his adminiſtration, by ſhewing you that *univerſal good* is the *end* or final cauſe of the whole creation, diffuſing itſelf every where continually into all things, in proportion to their ſeveral capacities of receiving and participating in it. It will teach you at the ſame time that the ſeveral operations in nature are carried on by means independent of all human counſel or direction, uncontroulable by any human power or authority, and far tranſcending all human abilities to plan, to manage, or to execute. You will diſcover ſome of thoſe laws by which the SOVEREIGN LEGISLATOR governs the corporeal univerſe, and by which he maintains it in undiminiſhed vigour, and undecaying beauty, through all ages, for the good of all beings capable of enjoying any ſhare in the manifold and various goods with which it abounds.

With ſuch proſpects before you I inſure myſelf the moſt unremitted attention, and that you will not ſuffer yourſelves to be diſcouraged by any apparent difficulties, but follow me with pleaſure while I am endeavouring to trace the operations of nature through all their multiplied proceſſes.

It has been a queſtion among philoſophers, whether the elaſtic power of the air is capable of being deſtroyed or diminiſhed: there is reaſon, however, to think that it's elaſticity may be conſidered as nearly perfect, becauſe a maſs of air that has been compreſſed by any given force re-eſtabliſhes itſelf as ſoon as that forces ceaſes to act, and that ~~completely,~~ regaining the ſame bulk it had before the compreſſion. There are ſeveral experi-

ments which prove that this elaſticity is not changed, either by the force or duration of the compreſſion; for with whatever force it be compreſſed, or however long it may be kept in a ſtate of compreſſion, it loſes nothing of it's original force. Meſſrs. Boyle and Deſaguliers made ſeveral experiments in order to diſcover how long the air would retain it's ſpring, without being able to obſerve any ſenſible diminution. M. Roberval incloſed air in a wind-gun, and preſerved it therein for 16 years; when he found, that it's expanſive force was the ſame as if it had been recently compreſſed. It muſt however be obſerved, that there are other experiments which ſhew, that in certain caſes the elaſticity of the air may be injured, and that it may alſo be vitiated by admixture with ſome peculiar ſubſtances.

OF THE RARIFACTION OF THE AIR.

Heat applied to a maſs of air produces two effects: if the air is ſo ſituated as to have room to expand, it rarifies it, or makes it occupy more ſpace; if it be incloſed and has not room to expand, heat increaſes it's elaſticity, and that ſo much the more as the preſſure is greater. To ſhew you that heat makes the ſame quantity of air occupy a larger ſpace, I take this glaſs tube, which is ſealed at one end, and nearly of an equal diameter throughout; I plunge the ſealed end into boiling water, and keep it there till it has attained as much heat as the boiling water can communicate to it; I now take it from thence, and inſert the open end into quickſilver, which I have previouſly warmed that it may not break the glaſs; you obſerve that I hold the tube nearly in an horizontal poſition, and that the mercury riſes in the tube in that proportion as it and the air within it cools: when it is perfectly cooled (to the freezing point) you will find one third of the glaſs tube filled with quickſilver,

 and

and two thirds with air. If I ſhould again transfer it to the veſſel of boiling water, the heat thereof would again expand the air, and make it occupy the whole length of the tube. From this experiment you will deduce the following inferences: 1. That heat augments the volume of air. 2. That a quantity of air compreſſed by the weight of the atmoſphere, and condenſed by the cold of ice, is to the volume of the ſame air rarified by the heat of boiling water as 2 to 3.

In repeating theſe experiments, you may find ſome variations, for the reſult will differ with the preſſure of the atmoſphere, which you know is continually varying, but humid air will occaſion ſtill greater deviations. The effect of a ſmall quantity of moiſture may be proved by a very ſimple experiment, that you may repeat when diſtant from any philoſophical apparatus. I took an empty glaſs phial that I had carefully dried within ſide, and inverted it in this water when it was boiling, and it has remained there till the air and water are perfectly cool, and you ſee that the phial is now filled about one-third with water, ſhewing that ſo much of the air was expelled by the heat, and conſequently that the air was expanded in that proportion. But by the addition of a ſmall quantity of water to wet the inſide of the phial, the air will be totally expelled, and make ſo perfect a vacuum, that when all is cool the phial will be entirely filled with water.

Heat increaſes the elaſticity of the air, in proportion to the incumbent preſſure, if the expanſion thereof be prevented. Take a glaſs tube between four and five feet in length, and about one-tenth of an inch in diameter, bent at bottom, and terminating in a thin glaſs globe five inches diameter, filled with common air; pour as much mercury into the tube as will rather more than fill the

the curved part thereof; and when the tube is vertical the mercury will be of an equal height in each branch of the tube: now it is plain that this could not be the caſe unleſs there was an equal preſſure on each end of the mercury, the denſity of the air within the ball being a counterballance to the preſſure of the atmoſphere. Let us ſuppoſe this preſſure to be equal to a column of mercury of 28 inches; on plunging the ball into boiling water, the mercury will riſe about $9\frac{4}{12}$ inches above the level in the longer arm, which is one-third of 28 inches. When the whole is cool, pour into the tube as much mercury as will form a column of 28 inches above the level; conſequently the air in the ball now ſuſtains a double atmoſphere: plunge it again in boiling water, and the mercury will be raiſed $18\frac{8}{12}$ inches above the point it was at before the immerſion: now $18\frac{8}{12}$ is the third of 56 inches, the preſſure ſuſtained by the air in the ball; ſo that this air then counterballances a weight equal to a column of mercury $74\frac{8}{12}$ in height: namely, the weight of the atmoſphere, 28 inches of mercury, and $18\frac{8}{12}$ inches, to which this was raiſed. It is evident therefore, from this experiment, 1ſt, That heat increaſes the elaſtic force of the air in proportion to the incumbent preſſure. 2d, That the heat of boiling water increaſes the elaſtic power of the air one-third of the incumbent preſſure. In the ſame manner you will find that the elaſticity of the air is weakened, and that it contracts into leſs ſpace by immerſion in cold or freezing mixtures.

It is plain from what has been ſaid, that the ſame degree of heat will expand air more in proportion, as the compreſſing force is removed. When a flaccid bladder is placed under the receiver of an air-pump, and the compreſſing force is withdrawn by exhauſtion, the air included in the

bladder expands and ſtretches it, in the ſame manner it would do, if the bladder were expoſed to the heat of a fire. Hence you may perceive why the vacuum of an air-pump produces ſo many of the ſame effects with actual fire.

It is neceſſary to obſerve to you one or two circumſtances concerning the experiment with the bent tube and the ball, as they occaſion ſome difference in the reſults. 1. As the mercury which riſes in the longer leg of the tube diminiſhes the quantity in the ſhorter tube, it leaves the air more room to expand. 2. Becauſe the bulk or ſize of the ball is increaſed by the heat of boiling water, which gives the air contained therein, more room alſo to expand, and thus leſſens the denſity thereof, and prevents the elaſtic force being ſo much augmented as it would otherwiſe have been by the heat of the water. Theſe circumſtances are mentioned to you, to ſhew you with what care and caution every philoſophical inquiry ſhould be purſued, and that the moſt minute circumſtances are to be attended to; even the irregularities obſerved in making any experiment ſhould be communicated, that others may know what has happened, and what they may expect to meet with in the courſe of their future inquiries. Improvements of every kind advance by ſlow degrees; and it is not until things have been viewed in every poſſible light, that error can be diſcovered, the point in queſtion clearly aſcertained, and the branches of philoſophy depending on the experiments you are making, be brought nearer to perfection.

I ſhall now proceed to apply the experiments you have ſeen, that you may perceive their uſe to mankind; and though ſome of them may have appeared to you of little importance, I hope ſoon to convince you, that even in the common avocations of life, you will often have occaſion to refer to the

conſequences

consequences naturally arising from them. It is an excellent remark of an able writer, "That "things remote from common observation are at "first indistinctly seen, like the distant objects in "a prospect. We are in doubt whether they are "hills or clouds which appear in the skirts of the "horizon; but when we draw near to them, we "find they are no vapours, but firm land fit for "culture and inhabitation."

That admirable property of the air, whereby it expands with heat, and contracts with cold, is one of the principal causes of winds. When the air in any place is rarified, the surrounding air, which is more dense, rushes in to supply the vacuity. Air in any one place being heated becomes lighter, and ascends; the surrounding air, being heavier and colder, supplies it's place. The air of any place being therefore heated, and rarified by the sun's rays or any other cause, the air of a colder region will press into that place, with a degree of violence equal to the rarifaction. On the other hand, if from any cause it becomes colder, it contracts into a smaller space, and the warmer circumjacent air rushes into the place, to keep up the equilibrium of nature.

Of the causes and nature of winds I shall treat more largely in a future lecture. To render the circulation of air evident, I shall mention an easy experiment which you may make on the first convenient opportunity. Let the air of a room be heated by a good fire, while the air of a contiguous room is cold; then let the door between the two rooms be opened, and the cold air being heaviest, will come into the heated room by the lower part of the door-way; the heated air will go out into the cold room by the upper part of the door-way: the direction of these currents of air may be seen by the direction of the flame of a candle, which

will be driven inwards or towards the heated room, if held near the bottom of the door-way; outwards, if held near the top; whilſt in the middle, there is little or no motion, the flame remaining perpendicular. This experiment further proves the rarifaction of air by heat, but it ſhews alſo, that it is the property of rarified air to aſcend.

If a room with a fire in it be perfectly cloſed except the chimney, the air therein would ſoon be rendered unfit for reſpiration, and the fire itſelf would ſoon be extinguiſhed. Hence it appears how improper it is, to keep the room of thoſe who are unwell or convaleſcent, too cloſe. The luxury and effeminacy of this age is ſtudious to ſtop up every crack, and exclude, as much as may be, every breath of air; wrongly conſulting preſent indulgence, at the expence of future eaſe and comfort. Children and young people are the moſt ſuſceptible of the ill effect of a cloſe air, and ſhew it by turning ſick, and complaining of the head-ach; and they who by practice feel leſs preſent inconvenience, are ſlowly loſing their complexions and deſtroying their conſtitutions, which are never more invigorated than by the coldneſs and purity of the morning air. It is a common obſervation, and a true one, that the body is ſtrongeſt and the ſpirits moſt active, in ſharp froſty weather, when fire burns the brighteſt; therefore if you are wiſe, you will be forward to expoſe yourſelves to the freſhneſs of a cool air, that you may have the uſe and enjoyment of your faculties, while others are deſtroying the powers of life by the debilitating ſleep of the morning hours, and the ſickly warmth of a cloſe apartment.

Many people imagine, that fire will purify contaminated air, by deſtroying the noxious particles that are mixed with it, and thus render it fitter for reſpiration: this however is not true, for

fire,

ſire, and combuſtion in general, is ſo far from purifying air, that it actually contaminates a prodigious quantity; ſo that even a lighted candle kept in a cloſe room, to which the external air has not free acceſs, renders the air of that room extremely noxious. But a fire kept up in a room or apartment where the air is tainted, as in hoſpitals, &c. will purify the apartment, by promoting a circulation of freſh air, to expel that which is infected.

OF SMOKY CHIMNIES.

Among the various inconveniences of life, there are few more troubleſome than being obliged to dwell in a ſmoky houſe. Smoke is a vapour offenſive to the ſenſes, and prejudicial to the health: it deſtroys all domeſtic enjoyment, ſoon tarniſhing the moſt beautiful decorations of a room, and ſpoiling the furniture. Numerous have been the contrivances, and immenſe the ſums of money expended, to ſecure the enjoyment of a fire, without the annoyance of ſmoke. Men of the firſt abilities have not thought this ſubject unworthy of their attention; and among thoſe who have endeavoured to remove the evils attending a ſmoky chimney, you will find the names of Deſcartes, Deſaguliers, Anderſon,* and Franklin.

The author of a paper in the Plain Dealer, aſſerts, that of the various perverſions of abilities, there is none that makes a human being more ridiculous, or more dangerous in it's conſequences, than that of attempting to *ſtir a fire* without judgment; to prevent which he lays down the following rules: 1. Stirring of a fire is of uſe, becauſe it makes a hollow where the air being rarified by the adjacent heat, the ſurrounding air ruſhes

* See Dr. Anderſon's Practical Treatiſe on Chimnies.

into this vacuum, and gives life to the fire, and carries the flame with it. 2. Never ſtir a fire when freſh coals are laid on, particularly when they are very ſmall, becauſe they immediately fall into the vacuum, and therefore ruin the fire. 3. Always keep the bottom bar clear. 4. Never begin to ſtir at top, unleſs when the bottom is quite clear, and the top only wants breaking.

You have already ſeen, that air has a conſtant tendency to preſerve an equilibrium; ſo that if the weight of it be diminiſhed in one place, the heavier air ruſhes in from all ſides, till the equilibrium be again reſtored. I have ſhewn you, that heat will diſturb this equilibrium very conſiderably, that it expands the air, and makes the ſame quantity occupy a much larger ſpace, and thus renders it much lighter. When a fire is kindled in a room, it heats and rarifies the air contiguous to it, which becomes conſequently lighter than the ſurrounding air, and therefore aſcends into the atmoſphere, till it finds or meets with air of the ſame gravity with itſelf, and the air in the room which is lower and more denſe, ruſhes in to ſupply it's place, and being there heated and rarified, it aſcends in the ſame manner, carrying with it the ſmoke ariſing from the coals or wood: the fire is fed and preſerved by this conſtant draught and circulation of air.

By this current of air, the machine called a *ſmoke-jack* is put in action. It conſiſts of a circular ſet of vanes diſpoſed obliquely to the courſe of the air, like the ſails of a good windmill: theſe are fixed into a vertical ſhaft and ſpindle that communicate with ſome wheel-work; theſe vanes are turned round with great velocity, when the fire burns briſkly, the ſtream of air preſſing ſucceſſively on the vanes, as a ſtream of water on the floats of a water-wheel. This may be illuſ-

trated

trated by an entertaining experiment: here is a paper lanthorn adorned with figures, and fixed to a light circular frame of ten vanes, each of them about four or five inches long, and about one and an half broad. The center of theſe is hung on a fine upright pivot. I put a lighted candle under the vanes; in a little time the air heated by the candle will riſe, and by it's ſucceſſive ſtrokes againſt the vane, make the lanthorn revolve with conſiderable velocity.

This circulation is evident to every one, and you muſt all know how much fire is quickened and increaſed by a blaſt of air. It is an eſtabliſhed law of nature, that as ſoon as a fire begins to ſpread itſelf, a ſtream of air ruſhes in from all ſides to ſupport it; and the larger the fire, the ſharper is the indraught of the air, which ſupplies the fire with freſh life and vigour: between the two a *double* motion is maintained of *fire outwards* and *air inwards*; that the matter of fire goes outwards is evident, 1ſt, from the ſhadow which any opake body caſts behind it, by intercepting this matter in it's courſe; 2dly, from the heat propagated through the air, and which, at a conſiderable diſtance from the fire itſelf, will act as fire, and inflame bodies when it is reflected from a concave ſpeculum. The current of air inwards you will perceive by holding a ſilk handkerchief, or any other light body near the fire, as well as by the ruſhing of the air through all the joints and apertures of the doors and windows of a room heated by a fire.

If you place any burning matter under a receiver not exhauſted of it's air, the ſmoke will riſe up perpendicularly and with conſiderable velocity; but when the air is exhauſted, the ſmoke will either ſink down, or hover as an atmoſphere about the ignited body; proving that the ſmoke does

does not ascend from any innate quality, but is impelled or forced up by a dense and active fluid.

A high chimney is said to draw best, and to you the reason will be evident, for the higher the chimney, the greater is the difference between the column of heated air within the chimney, and a column of the same diameter and altitude without. For the air continues warm and highly rarified till it intermixes with the common air at the top of the chimney, and is consequently throughout it's whole length lighter than the same bulk of common air; it is clear, therefore, that the longer these two columns of unequal gravity are, the greater will be their difference in their weight, the air will ascend with greater celerity, and the chimney will act better.

There is another material circumstance towards promoting a good draught in the chimney, *making the air that is forced through pass as near the fire as possible*. It is the heated and rarified state of the air which causes it's ascension; the more air is heated, the greater will be the force and velocity with which it ascends; and air will be more heated, the nearer it approaches the fire when it enters the chimney: in other words, the lower the mantle of the chimney is, the more readily will the smoke ascend, being more rarified, and moving with great velocity.

But *fresh air must be admitted into the apartment in sufficient quantity to supply what is thus carried away, and consumed by the fire*, otherwise the air in the room would be soon exhausted, and lighter than the external air at the top of the chimney, and the smoke would therefore be soon dispersed in the room; thus from the consideration of the action of the air and fire, we are naturally led to treat of the causes of smoky chimnies; and I persuade myself, that you will be enabled yourselves, from the

the principles already laid down, when the caufe is fhewn you, to point out the remedy.

The general caufe of fmoky chimnies in a new houfe is the want of air. The workmanfhip of the rooms being all good, the joints of the boards of the floors all tight and true; the doors and fafhes being alfo worked with truth, and fhutting with exactnefs, there is no paffage left for the air to enter except by the key-hole, and that is often ftopped by a dropping fhutter. Now it muft be plain to you, that in this cafe there can be no circulation of air, to fupport the place of that which is rarified by the fire; and confequently that there can be no current to prevent the fmoke coming into the room.

To ftop every crevice in a room, and yet fuppofe that a chimney can carry up the fmoke, is to require inconfiftencies, and expect impoffibilities; yet often on this account alone, has the owner of a new houfe been feen in defpair, and ready to fell it for much lefs than it coft; and, often alfo much expence has been laid out to effect a cure to little purpofe, as thofe who were employed were ignorant of the principles on which the cure muft be founded.

You will eafily afcertain whether this be the caufe of the chimney's fmoking; for if the opening a door or a window enables the chimney to carry up all the fmoke, it is clear that want of air from without is the caufe of it's fmoking.

Your mind has already fuggefted to you, that the only poffible means of remedying this evil, muft be by a continual fupply of frefh air, and we have only to confider how this fupply may be procured with the feweft inconveniences. Here, however, it will be neceffary to obferve to you, that in all rooms where there is a fire, the body of air that is warmed and rarified before the chimney, is con-

tinually changing place, and making room for other air to be warmed in it's turn. Part of it is driven up the chimney, the reſt riſes and takes place near the ceiling. If the room be lofty, the warm air remains above our heads, as long as it continues warm; and we are but little benefited by it, becauſe it does not deſcend till it is cooler.

The difference in the climate, between the upper and lower parts of a lofty room, is greater than you would at firſt imagine, but which you may eaſily aſcertain by a thermometer, or going up a ladder till your head is near the ceiling. It is among this warm air that the wanted quantity ſhould be admitted, for by mixing with the ſurrounding air, the coldneſs thereof is abated, and the inconveniencies that would otherwiſe ariſe from it's admiſſion, are hereby rendered almoſt inſenſible; and this may be eaſily effected, by cutting a crevice in the frame at the upper part of the ſaſh, which may be concealed by a thin board ſloping upwards, to give the air that paſſes through an horizontal direction along and under the ceiling. In ſome houſes the air may be admitted by a crevice in the wainſcot, or plaiſtering near the ceiling and over the opening of the chimney; this, where practicable, is to be choſen, becauſe the entering cold air cools the warmeſt air as it riſes from before the fire, and is ſooneſt tempered by the mixture. It may alſo be effected by a pipe or tube communicating with the ceiling, admitting air there, and leading from thence downwards on the outſide or inſide of the building, the lower end communicating with the external air. The cold air would come in at the lower aperture, aſcend into the room, and imperceptibly mix with the heated air, and diſperſing itſelf through the room to the fire, carry off the foul air, and ſupply the room with a ſucceſſion of that which is pure and wholeſome.

2. *Smoke*

2. *Smoke descends into the room when the opening of the chimney is too large, that is, when it is either too wide, too high, or too deep.* Confidered philofophically, the apertures of the chimnies fhould always be proportioned to the height of the funnel. The openings of the longeft funnels may always be larger than thofe with fhorter funnels.

When the chimney-piece is too high, a great quantity of cold air can pafs between the mantle and the chimney, without being rarified by the fire, confequently the contents of the funnel differ lefs in weight from the furrounding air, and the power of afcending, or draught of the chimney, is confiderably leffened, if not deftroyed.

If the fire-place be too deep, the grate ftanding far back, the air is not fufficiently heated, nor will the evil be cured by bringing the grate forward, and leaving a vacuum behind.

When the opening is too wide, a great deal of air paffes the fides of the grate without being much heated; wherever a quantity of cold air is fuffered to pafs the chimney, the motion of the fmoke is checked and ftifled at it's firft fetting off, and the circulation of the external air being deftroyed the fmoke defcends.

Thefe defects may be remedied by a proper contraction of the opening of the chimney, and by filling up the vacancies behind and on each fide of the grate, fo as to let no air enter from below but what comes immediately through or before the fire, whereby the air will be more heated and rarified, and the funnel made warmer fo as to maintain a good draught at the opening. But as in a wide chimney a quantity of cool air often enters at the two corners of the mantle, and thus finds it's way into the chimney without coming near the fire; to remedy this, place a fheet of milled iron on

on each ſide, within the mantle, as low as poſſible, and ſlanting upwards towards the middle of the chimney. This method is ſtill more efficacious, if one of the plates be placed a little lower than the other, and made ſo long that the ends of one go beyond the end of the other thus, $\wedge$. Thus will every particle of air be obliged to paſs before the fire, and be rarified. It may be proper to obſerve here, that the openings may be made too ſmall, ſo that the entering air operating too violently and directly on the fire, will ſtrengthen the draught, but will alſo conſume too much fuel.

3. *Another cauſe of ſmoky chimnies is having too ſhort a funnel.*

There are ſome ſituations where a ſhort funnel cannot be avoided; the only remedy in this caſe, is to contract the opening of the chimney, ſo as to oblige all the entering air to paſs through or very near the fire.

4. *It is very common for one chimney to overpower another, and thus bring down the ſmoke.*

Thus in a middle ſized room with two fireplaces, if the doors and windows be ſhut, and a large briſk fire be made, it will ſoon bring the air down the other chimney with ſuch force as to put out a candle: if fires are kindled in both, the greater and ſtronger fire will overpower the weaker, and draw air down the funnel thereof to ſupply it's own wants; this air in deſcending will drive down the ſmoke of the other fire, and force it into the room.

If, inſtead of being in one room, the two chimnies are in two different rooms communicating by a door, the caſe is the ſame whenever that door is open. A kitchen chimney, in a tight houſe, will, when the doors are open that communicate with the ſtair-caſe, overpower every other chimney in the houſe, and draw the ſmoke down them.

The

The only remedy here is to ſupply every chimney with as much air as is neceſſary for it's own conſumption, which may be effected by the means already pointed out.

5. *The ſmoke is often driven into a room by the improper and inconvenient ſituation of a door.*

For as the ſmoke is carried up the funnel by the continual and ſucceſſive preſſure of the air that enters at the fire-place, if this air be diverted or driven away from the chimney, the ſmoke will be carried away with it into the room; indeed any circumſtance that turns the current of air from the under part of the fire, will be an aſſured cauſe of producing ſmoke in the room. The variety of caſes that occur under this head, are too many to be enumerated in this lecture. The remedies are either to place an intervening ſcreen, or to ſhift the hinges of the door.

6. *Sometimes an apartment is filled with ſmoke when a fire is kindled in an adjoining chimney, and no fire in the incommoded room, although it does not ſmoke when it has a fire burning at it's own grate.*

This generally ariſes firſt from the wind driving the ſmoke down the funnel of the adjoining chimney along with the cold air, which cold air may be forced down by a guſt of wind or by other cauſes; this may be remedied by a circular partition of about three inches between the funnels at top.

Or it may ariſe from holes in the partition that divides the funnels; for this there is no perfect cure, but pulling down the chimney to the part where the holes are, and rebuilding it in a ſound manner. You may be relieved, by making uſe of a chimney or ſmoke board, fitted exactly into the aperture of the chimney.

7. *If the funnel be made ſo narrow as not to permit the ſmoke to paſs freely, it is checked by the ſudden*

ſudden contraction at the mouth of the chimney, and will be forced into the room before it can overcome the reſiſtance to it's aſcent. Every chimney ſhould be made wide enough to carry off all the ſmoke ariſing from the fire uſually burned in it.

The moſt obvious cure is what can ſeldom be effected without much inconvenience and expence, that is, building an additional flue to carry up the ſurplus of the ſmoke; but if the ſituation will not admit of this, the fire-place may be contracted both in breadth and height, and a ſmaller grate uſed, and the funnel heightened. If this only cures in part, and the chimney ſtill ſmokes in part, a blower, or front plate of braſs or iron, to put on and take off at pleaſure, muſt be uſed.

8. *The ſmoke is often drawn down by a wrong poſition of the houſe with reſpect to external objects, as when tops of chimnies are commanded by higher buildings, or by a hill, &c.* which by interrupting the courſe of the air make it aſſume various directions, and drive the ſmoke down the chimney in a ſtream, or wheeling about in eddies, prevent it's aſcent.

Hence it is that low houſes, when contiguous to high objects, are in danger of being diſturbed with ſmoke. If the contiguous object be not very high, the diſorder may be cured by heightening the chimney; but if it be very high, it will be neceſſary to place a turncap, or ſome ſuch other contrivance, on the top of the chimney, as will prevent the wind from entering it, while it leaves a free paſſage for the ſmoke.

9. *The ſmoke will ſometimes be driven down by ſtrong winds paſſing over the top of the funnels.* This caſe is moſt frequent where the funnel is ſhort, and the opening turned from the wind.

When a violent current of air, or a ſtrong wind, paſſes over the top of a chimney, the parti-

cles thereof acquire ſo much force, and move with ſo much rapidity in a direction nearly horizontal, as to prevent the riſing light air from iſſuing out at the top of the chimney, and ſome of the current is alſo often driven down the chimney. Where this happens often, a turncap will be the beſt remedy.

Chimnies, whoſe funnels go up in the north wall of a houſe, and are expoſed to the north winds, do not, in general, draw ſo well as thoſe in a ſouth wall, becauſe when rendered cold by thoſe winds they check the ſmoke.

Chimnies incloſed in the body of a houſe, are better than thoſe whoſe funnels are expoſed in cold walls.

Chimnies in ſtacks draw better than ſeparate funnels, becauſe the funnels, that have conſtant fire in them, warm the others in ſome degree that have none.

All funnels ſhould have a winding direction as near the top as poſſible, which would in a great meaſure prevent any ill effects from ſtrong or ſudden guſts of wind.

I have now ſhewn you the general cauſes which prevent the free aſcent of ſmoke; in ſome caſes two or more of theſe cauſes may operate at the ſame time.

Dr. Franklin obſerved a curious circumſtance relative to chimnies, which does not ſeem to have been noticed by any one elſe, and which is worthy of your attention, namely, that in ſummer time, when no fire is made in the chimnies, there is, nevertheleſs, a regular draught of air through them, paſſing upwards from about five or ſix o'clock in the afternoon, till eight or nine o'clock the next morning, when the current begins to ſlacken and heſitate a little for about half an hour, and then ſets as ſtrongly down, which it continues to

do till towards five in the afternoon, when it slackens and hesitates as before, for about half an hour, and gets a steady upward current for the night. The hours vary a little as the days lengthen and shorten; they are also varied by sudden changes in the weather. In summer time there is a great difference in the warmth of the air at mid-day and mid-night, and of course in it's specific gravity, as the more the air is warmed the more it is rarified. The funnel of the chimney being generally surrounded by the house, is protected both from the heat of the sun's rays, and the coolness of the night; this mean temperature it communicates to the air contained in it. If the outer air is cooler than that in the funnel, it will, by being heavier, force it to rise, and go out at the top; what supplies it's place, being warmed by the funnel, is in it's turn also forced up the chimney, and so the current continues till the next day, when the sun warms the air: and the funnel being now cooler than the air that enters it, that air is rendered heavier than the surrounding air, and therefore descends.

It will be easy for you to make a few experiments on this subject, and thus render the doctrines it contains familiar to your minds: for this purpose furnish yourselves with a number of small representations of rooms; let each of them be composed of five panes of window-glass framed in wood at the corners, with proportionable doors, moveable glass chimnies, and openings of different sizes, and different lengths of funnel; the rooms may be so contrived as occasionally to communicate one with the other, and thereby form different combinations; fourteen or fifteen pieces of *green* wax taper, stuck together in a square, would make a strong fire for a small glass chimney, and when blown out would continue to burn and give smoke

as long as desired. With such an apparatus, all the operations on smoke and rarified air, may be made with ease, and the effects would be seen through the transparent sides.

From what has been said on the methods of curing smoky chimnies, you will see the importance of experimenting in philosophy; and that while we are investigating one subject, new light is often thrown upon another. You little thought of the relation of the experiments on rarified air, to that of our common fires: it is thus that something unexpected often starts up in the course of our inquiries, and the accidental discovery is often of more importance than the original business of the research. To an attentive observer, scarce any thing will pass without it's use, and without making some addition to science.

Chimnies have not been of long date in England, and the smoke was let through a hole in the roof. There is extant in the records of one of Queen Elizabeth's parliament, a motion made by a member, reciting, "That many dyers, brewers, "smiths, and other artificers, had of late taken to "the use of pit-coal, for their fires, instead of "wood, which filled the air with noxious vapours "and smoke, very prejudicial to the health, par-"ticularly of persons coming out of the country; "and therefore moving, that a law might pass to "prohibit the use of such fuel, at least during the "session of parliament, by those artificers." It was not then used in private houses, the unwholesomeness was the objection; fortunately the inhabitants got over this objection, and now think it rather contributes to render the air salubrious, as they have had no general pestilential disorder since the general use of coals, though before that use they were frequent.

OF CONDENSED AIR.

You have ſeen, that in a given quantity, air may be expanded into a larger ſpace, or contracted into a ſmaller. I have explained the nature of the air-pump, by which it is rarified and exhausted, and now proceed to ſhew you that philoſophy has engines, not only to rarify, but alſo to condenſe the air, and thus increaſe it's ſpring by artificial compreſſion.

This machine is called a condenſing engine: it conſiſts, 1ſt, Of a ſyringe to condenſe, or rather to throw freſh air into the ſame ſpace. 2d, A ſtrong receiver to hold this air. 3d, A guage to meaſure the degree of compreſſion. The receiver is confined down to the plate by ſcrews, that it may not be forced up, and thus let the air eſcape. (*fig.* 1, *pl.* 2.)

As much air is thrown into this receiver, at every ſtroke of the piſton, as the ſyringe will contain; this will be evident to you when you conſider the conſtruction of this ſyringe. When the piſton (which is ſolid) is drawn from the bottom, it leaves a vacuum under it; till it gets beyond this ſmall hole near the top of the barrel, the external air ruſhing through that hole into the barrel fills it with air; now the valve in this ſyringe opening downwards, contrary to what you obſerved in the air-pump, when I puſh the piſton down, all the air contained in the barrel is forced into the receiver, and cannot return; the air, therefore, therein is compreſſed, and may be thrown in till it is rendered ſo denſe, and it's ſpring as great as the ſtrength of the machine will bear. You may always know the degree of condenſation by the mercurial guage:—when the quickſilver has gone through half the ſpace between it and the end of the

the tube, the air is of a double denſity; when it has paſſed two-thirds of the ſpace, the air is three times denſer, and ſo on, for *the denſity of the air is always inverſely as the ſpace it occupies.* As the quantities forced in by each ſtroke of the piſton are equal, the quantities in the barrel, and conſequently the degrees of condenſation, increaſe in an arithmetical progreſſion. If the receiver be not made very ſtrong, it would be ſoon torn aſunder by the air's elaſtic force, which we have already ſhewn you to be as the compreſſing force.

Mr. Boyle has left us a great number of experiments made with a condenſing engine, which ſhew that animals may be killed by too great a condenſation of air; that when condenſed to a moderate degree, he found them to live longer therein than in common air; that it ſcarcely affected inſects and frogs; that mouldineſs was promoted nearly in proportion to the degree of condenſation; and that vegetation was not injured thereby.

If the air be exhauſted from two hemiſpheres, of three inches and a half diameter, it will require a force equal to about one hundred and forty pounds to ſeparate them. But if the ſame hemiſpheres be placed under the receiver of the air-pump, without exhauſting the air from them, and ſo much air be thrown into the receiver as to render it double the denſity of the external air, it will require the ſame weight to ſeparate them; a further proof of the atmoſpheric preſſure. But if the hemiſpheres were exhauſted before they are put under the receiver of the condenſing engine, and then the air is doubled in denſity, it will require a weight of two hundred and eighty pounds to ſeparate them; ſo that a double atmoſphere has the ſame advantage over a ſingle one, that the ſingle one has over a vacuum.

The ſound of a bell is much louder in condenſed than in common air.

A round phial, that would bear the preſſure of the atmoſphere, may be broken by condenſed air, the air being exhauſted from the inſide.

A bladder that will not break with the natural ſpring of the air, will ſoon be burſt by the increaſed elaſticity of condenſed air. Indeed the force of condenſed air may be increaſed ſo as to counteract the greateſt powers we can apply againſt it; and as the air from it's ſituation muſt be greatly condenſed in the lower parts of the earth, with the application of heat, it may have the moſt prodigious effects, producing convulſions in the body of the earth, and even a diſruption of the parts extending to the ſurface.

To this ſuſceptiblity of the air, of being *condenſed*, and of it's ſurpriſing *expanſive* force when this preſſure is taken off, we are indebted for the wind-gun, where, by great condenſation, the air gives motion to leaden bullets, after the manner of gunpowder. In the preſent mode of making them, a hollow ball is affixed to the breach of the gun, this holds the condenſed air, which is prevented from entering by a valve, which valve is governed by a ſpring. On diſcharging the cock the valve opens, but cloſes almoſt inſtantaneouſly, by means of a ſpring. The air that eſcapes forces out the ball with ſuch violence, that it will be driven to the diſtance of 60 or 70 yards, or even further. Several ſhot may be diſcharged without throwing freſh air into the condenſing ball; but the force, as you may infer from what has been already explained, leſſens at every diſcharge, the fluid being leſs compreſſed, and it's elaſticity of courſe weaker.

I ſhall now ſhew you how condenſed air, by it's

it's pressure on the surface of water, will give motion to it, and produce a pleasing artificial fountain, (*fig.* 13, *pl.* 3.) This fountain consists of a strong copper vessel, which is to be filled partly with water, partly with air; this pipe is long enough to reach nearly the bottom of the copper vessel: at the upper end of the pipe is a stop-cock. I fill the vessel about two-thirds with water, and then screw in the pipe; the junction is you see made air-tight, by means of an oiled leather; the air contained between the surface of the water and the top of the fountain, is at present of the same density with that of the atmosphere. I screw the condensing syringe to the upper part of the stop-cock, and by it throw air into the vessel, which, as it cannot return, forces it's way through the water into the upper part of the fountain, and there remains in a state of greater condensation than the outward air. Having thrown in as much as I think necessary, I turn the stop-cock, unscrew the syringe, and screw in it's place a jet or pipe, with a small aperture at top. I now turn the stop-cock again, to open the communication between the external air and pipe, and the water is immediately thrown up a considerable height by the pressure of the included air; the force with which it is thrown upwards is as the excess of the pressure of the included air above the external air; and as the pressure of the atmosphere is equal to a column of water thirty-three feet in height, if the included air is thrice as dense as the external, the height of the jet will be sixty-six feet; but in proportion as the quantity of water in the fountain is lessened, the air has more room to expand, it's elasticity is diminished, and it acts with less force upon the water.

To render this experiment more entertaining, the fountain is furnished with a variety of curious

jets, which may be ſcrewed in the place of that which is now at the top of the fountain.

Here is one that throws up a cork ball, which will ſometimes remain ſuſpended on the top of the water; it will often revolve on it's center, fall and riſe again, ſpreading the water all around.

Another jet is made of a hollow braſs globe, pierced with a number of ſmall holes tending to the center; the water ruſhing through theſe, with the directions in which the holes are made, forms a very pleaſing ſphere of water.

Among the variety of jets, ſome forming caſcades, revolving jets, &c. &c. there is none more ſtriking, or more pleaſing than one in the form of a croſs, in which the jets are ſo accurately at right angles to each other as to meet in that direction, which then changes, and takes another nearly intermediate with the former direction; illuſtrating very pleaſingly the doctrine of compoſition and reſolution of forces, in which you will be inſtructed in our mechanical lectures.

The condenſing fountain and it's jets are repreſented at *fig.* 12, 13, 14, 15, 16, 17, 18, 19. *pl.* 3.

It will not be improper, before we proceed further, to recapitulate to you the laws I have explained concerning the elaſticity of atmoſpheric air. 1ſt, I have ſhewn you that air may be condenſed by preſſure, and that the ſpace into which it is contracted is in the inverſe ratio of the preſſure; thus, if one pound weight contracts a quantity of air, which in a natural ſtate occupies the ſpace of twelve cubic inches, into a ſpace equal to ſix cubic inches, two pounds will reduce it into three cubic inches, three pounds into two cubic inches, &c. No experiments, that have been hitherto made, ſhew the ultimate limits of this condenſation; for after being compreſſed, as much as the

the inſtruments made for that purpoſe, would bear, it ſtill ſeemed capable of much greater compreſſion, by the application of a greater force. Neither *preſſure*, nor *cold*, nor any other means, have yet exhibited air as a *ſolid*, or even rendered it a *viſible fluid*.

2d, You have alſo ſeen that as air is contracted into a ſmaller ſpace by preſſure, ſo it expands into a greater ſpace when the preſſure that confines it is removed. The limits of this expanſion are not known, nor are there any experiments to ſhew, that when air has attained a certain expanſion, it is not capable of a greater.

3d, The elaſticity of the air does not ſeem to be impaired by a long and continued preſſure, ſo that if a given quantity of air is kept for a long time highly compreſſed or very much rarified, it will always return to the ſame given quantity, when put into the ſame circumſtances that it was in before the condenſation or rarifaction.

4th, Air is rarified by heat, and contracted by cold. *

5th, The weight of the atmoſphere is continually changing, ſo that if at one time it forms a counterpoize to a column of quickſilver of thirty inches, at another time it will ſupport a longer column, and at others one not ſo long.

I may now proceed to explain to you a few more of thoſe machines which depend on the ſpring and weight of air: among theſe there are none ſo neceſſary for you to be well acquainted with

* Colonel Roy concludes from his experiments (Phil. Tranſ. 1777, p. 704,) that ſixty-ſix degrees of Fareinheit's thermometer dilates the air 2.58090 thouſandths parts of it's bulk. M. de Sauſſure makes the ſame degree only dilate it 1.88615. M. de Sauſſure attributes this enormous difference in their reſults to the difference of capacities of the veſſels in which the experiments were made.

with as the different kinds of pumps. They are generally divided into two kinds: 1ſt, The common, or as it is often improperly called, the ſucking-pump. 2d, The forcing-pump.

OF THE COMMON OR HOUSE-PUMP.

This is ſaid to have been invented by Cteſebes, a mathematician, about 120 years before Chriſt. The operation of this pump depends on the preſſure of the atmoſphere; which being equivalent to 30 inches of mercury, or 34 feet of water on a given ſurface, it is plain that water cannot be raiſed by this ſpecies of pump, to an altitude greater than that of about 34 feet: this height varies, being a little greater or leſs, on account of the differences in the weight of the atmoſphere. It is ſeldom, however, applied to raiſing water above 28 feet, leſt the pump ſhould fail in it's performance. Here is a model of the common pump in glaſs, (*fig.* 22, *pl.* 1,) that you may ſee the action of the piſton and the motion of the valves. It conſiſts of a pipe open at both ends: this part which is larger than the other is called the body of the pump; in this there is a moveable piſton: the piſton you ſee fits ſo exactly to that part of the pipe wherein it works, that it does not let any air paſs between it and the pipe. The loweſt point to which the piſton can be depreſſed, and the higheſt point to which it can be raiſed, is called *the ſtroke of the piſton.*

Here are alſo two valves, both opening upwards; the one in the lower part of the pump, the other at the upper part of the piſton. I put the bottom of the pipe in water, and thruſt the piſton to the bottom of the barrel or body of the pump, pouring ſome water on it to keep the piſton tight. I raiſe up the piſton, which leaves a vacuum in the barrel, into which the air in the lower

lower part of the pipe will expand; the air in the pipe being thus rarified, and it's ſpring weakened by the expanſion, it preſſes leſs upon the ſurface of the water in the pipe, than the atmoſphere does on the ſurrounding water; conſequently the water will riſe in the tube till the air within is as denſe as that without, and thus reſt between two equal preſſures. I then depreſs the piſton, but the valve which opened to let the air come out of the pipe, will permit none to go back again; it therefore forces it's way through the valve in the piſton, and mixes with the common air. After a few ſtrokes the whole of the air is extracted, and then the water riſes through the valve, and is diſcharged by the piſton: the water will now continue to run out of the ſpout as long as I continue to work the pump. You ſee that every time the piſton is lifted up, the lower valve opens, and the upper one cloſes; but on depreſſing the piſton the lower valve cloſes, and the upper one opens: it is by this ſimple mechaniſm that we ſo eaſily raiſe water, and avail ourſelves of the preſſure of the atmoſphere; the piſton in riſing, lifting up all the water above it and diſcharging it, and while it riſes, more water paſſes through the lower valve to be lifted up at the next ſtroke of the piſton.

Though the preſſure of the atmoſphere will not raiſe water higher than 34 feet; yet when the water has once got above the piſton, it may be lifted thereby to any height, if the piſton-rod be made long enough, and a ſufficient degree of power or ſtrength be employed to raiſe it with the weight of water above the piſton.

If a pump admits or takes air at the lower valve, the water will fall down into the reſervoir, for the ſame reaſon that the mercury would fall out of the tube of a barometer, if the air was let into the top of the tube. If the water has been

out

out of a pump for ſome time, the leathers of the valves grow dry, and will neither open nor ſhut freely; the leather round the piſton grows dry alſo, and will not then fill exactly the cavity of the barrel. The mode uſed *to fetch the water again*, as it is called, is by pouring a pail-full of water down the pump, to moiſten the valves, and make them ſhut and open freely, and ſwell the leather round the piſton, ſo that it may fill the cavity of the barrel; when this is done, the pump will work as well as before.

The force required to work a pump, is as the height to which the water is raiſed, and the ſquare of the diameter of the barrel in which the piſton works.

Conſequently, if there be two pumps of equal heights, but the diameter of the one *twice* as large as that of the other, the largeſt will raiſe four times more water than the ſmaller one, and will require four times as much ſtrength to work it.

The diameter of the pump in any other part but where the piſton works, does not increaſe or diminiſh the difficulty of working it, except ſome difference occaſioned by friction, which is more in a narrow bore than a wide one. The handle acts as a lever, to give an advantage to thoſe who work the pump.

The longer ſtroke the pump makes, the more water it raiſes with the ſame power, leſs water being loſt by the ſhutting of the valve.

Here it may be neceſſary to obſerve, that though the preſſure of the air on the water in the well, &c. will raiſe this water, yet this aſſiſtance is counterballanced by the weight of the atmoſphere on the water thus raiſed on the piſton; ſo that the advantage obtained by this engine, is that of putting things into a more convenient and manageable form, and it will be well worth your while to remember

member this circumſtance, as you will find it take place in almoſt every other piece of mechaniſm.

OF THE FORCING PUMP;

Or that kind which raiſes water by the force of condenſed air.

Of this kind here is alſo a model, (*fig.* 21, *pl.* 1,) by which you ſee, that the pipe and body, or barrel of the pump, is the ſame as the preceding one, but that there is no valve in the piſton: at the bottom of the barrel there is a ſmall tube placed at right angles to the barrel of the pump; to the other end of this tube is cemented a ciſtern, into which the water is to be forced; from the top of the ciſtern there is a tube which goes nearly to the bottom thereof. You obſerve alſo two valves, one fixed near the bottom of the barrel, the other in the ſmall tube or forcing-pipe. This pump acts in the firſt place by the atmoſpheric preſſure, as the preceding; and then by forcing the water into this ciſtern, the air in which being condenſed, will preſs upon the water, and throw it up a conſiderable height, in the ſame manner you ſaw it act in the condenſing fountain.

I ſhall now work it to ſhew you the effect: when I lift up the piſton, the air between that and the water below having room, dilates itſelf, and preſſes leſs ſtrongly on the water, and a few ſtrokes will ſoon bring the water above the valve in the barrel. When the piſton deſcends, as the water cannot paſs through it, nor back again into the lower part of the pump, it is forced through the bent pipe and valve into the reſervoir or air-veſſel; the moment I raiſe the piſton again, this valve you ſee ſhuts, and prevents the water in the air-veſſel from returning.

Thus being by repeated ſtrokes forced into the air-veſſel, it gets above the lower end of this pipe,

pipe, and then begins to condenſe or crowd the air into a ſmaller ſpace; for as the ſmall pipe is fixed ſo as to be air-tight at the top of the reſervoir, and the air has no way of eſcaping but through it, that way is cut off when the end thereof is covered with water; the air is more and more condenſed as the water riſes, ſo much ſo, that you ſee by it's preſſure on the ſurface of the water it forces it through the pipe in a jet to a conſiderable height, while I ſupply it with water, by continually working the piſton: the higher the ſurface of the water is raiſed in the air-veſſel, the ſmaller you ſee is the ſpace into which the air is condenſed, and the more powerful it's action on the water, which it drives with greater force through the pipe; and as the ſpring of the air remains and acts while I am raiſing the piſton, the ſtream continues uniform as long as I work the pump.

Water may be raiſed by a forcing-pump to any height above the level of a river or ſpring, and machines may be contrived to work theſe pumps, either by a running ſtream, a fall of water, by horſes, or by ſteam.

The water-works at London-bridge exhibit a moſt curious engine of this kind: the wheel-work is ſo contrived as to move either way as the water runs; the engines are ſaid to raiſe above 140,000 hogſheads of water each day.

The engine uſed for extinguiſhing fires, acts as a common and forcing-pump, and raiſes water, as you have ſeen, to great heights, and with conſiderable velocity.

OF THE SYPHON.

This, though a ſmall inſtrument, muſt not be neglected: it conſiſts you ſee of a bent tube, one end of which is longer than the other. I immerge the ſhorter leg into this veſſel of water; I now draw

draw the air out of this tube by my mouth, and you ſee that as ſoon as the air is drawn out of the tube, the preſſure thereof on the water in the veſſel will force it up the ſhorter leg, over the bend, and down the other; and when I take my mouth away from the longer leg, it will begin to run out, and continue running till it is below the aperture of the ſhorter leg. The water is raiſed in the lower leg by the preſſure of the air, and if the legs of the ſyphon were equal, it would not run out, as there would be an equal preſſure on both ends, one counteracting the other; but when one leg is longer than the other, the water begins running from the exceſs of it's weight, and the continuation of the motion probably ariſes from the nature of a fluid ſubſtance; or as the preponderating weight in the longer leg renders the preſſure of the air on that leg leſs effectual than on the other, the water neceſſarily moves to that part where there is leſs preſſure.

The ſyphon may be diſguiſed ſo as to produce a great many entertaining and apparently surpriſing effects. Thus it may be concealed in a cup, (*fig.* 20, *pl.* 3,) which will hold the liquor contained in it till it has attained a certain height, when it will begin to run out, and continue ſo to do till the veſſel is emptied. Here is a cup with a figure ſtanding in the center; I pour water into the cup, and you ſee it remains there: it has now nearly reached the lips of the figure, and the ſyphon contained therein begins to act; the water riſes in the ſhorter leg by it's natural preſſure as high as it's own level: when it has got beyond the bend of the ſyphon, it is drawn away by the longer leg. There are many artful ways of concealing the ſyphon, and rendering it's effects more ſtrange and amuſing; ſometimes the ſyphon is concealed in the handle. This cup is generally called

called Tantalus's cup, from the fable of Tantalus, thus deſcribed by Homer:

There Tantalus along the Stygian bounds,
Pours out deep groans! (with groans all hell
abounds)
E'en in the circling floods refreſhment craves,
And pines with thirſt amidſt a ſea of waves;
And when the water to his lips applies,
Back from his lips the treacherous water flies.
Above, beneath, around his hapleſs head,
Trees of all kinds delicious fruitage ſpread.
There figs, high-dyed, a purple hue diſcloſe;
Green looks the olive, the pomegranate glows:
There dangling pears exalted ſcents unfold,
And yellow apples ripen into gold.
The fruit he ſtrives to ſeize, but blaſts ariſe,
Toſs it on high, and whirl it to the ſkies.

The ſyphon affords a very probable ſolution of the nature of *intermitting ſprings*, which I muſt illuſtrate by a diagram. Let HHKB, (*fig.* 2, *pl.* 4,) repreſent a cavity in the bowels of a mountain, from the bottom of which proceeds the irregular cavity BDET, forming a ſyphon. Now, if by means of rain, ſprings, or any other cauſe, this cavity begins to fill, the water will at the ſame time riſe in the leg of the ſyphon or cavity, till it has attained the horizontal level, when it will begin to flow out by means of the leg DET, and will continue to riſe and increaſe in the quantity diſcharged, as the water riſes higher, till at length the ſyphon will pour out a full ſtream, and thus empty the cavity. The ſtream will now ceaſe till the cavity fills again, when it will exhibit the ſame appearance; and theſe periodical returns of flood and ceſſation will be regular, if the filling of the cavity be ſo; but the intervals of

of the return muſt depend on the dimenſions of the cavity, and many other circumſtances.

Many inſtances of this kind occur in nature. At Graveſend there is ſaid to be a pond, out of which the water ebbs all the time the tide is coming into the adjacent river, and flows during the time that the tide is going out. This appearance probably ariſes from a ſubterraneous reſervoir, equal in capacity to the quantity of water that riſes and falls in the pond: between this reſervoir and the pond there may be a natural ſyphon, by which they communicate with each other, and act as we have already explained; and a ſecond natural ſyphon may, in the ſame manner, convey the water away from the pond, when it is filled to a certain height.

At Lambourn, in Worceſterſhire, there is a brook which in ſummer-time receives a flow of water ſufficient to turn a mill, but in winter it runs a very inconſiderable ſtream. It is probably occaſioned by a large ſubterraneous reſervoir, filled to a certain height by the winter rains, ſnows, &c. and that then a natural ſyphon takes effect, and brings away the water in a ſtream equal to it's bore, till it has emptied the reſervoir as far as it's action reaches.

This is illuſtrated by this apparatus, (*fig.* 4, *pl.* 3.) The upper box (A) is filled with water; a ſmall pipe carries water from this box to the ſpring at G, where it will run off conſtantly. Another ſmall pipe (D) carries water from the upper box to the under one (B) or well, from which a ſyphon proceeds that joins with the former pipe: the bore of the ſyphon is larger than the bore of the feeding pipe (D); as the water from this pipe riſes in the well B, it will alſo riſe as high in the ſyphon E e F; and when the ſyphon is full to the top (e) the water will run over the

 bend

bend and go off at the mouth, and will make a great ſtream at the ſpring, and that ſtream will continue till the ſyphon has carried off all the water from the well; the ſyphon carrying off the water faſter than the pipe brings water to it; and then the ſwell will ceaſe, and only the water from the ſmall pipe will run off, till the pipe fills the well again, when the operation will recommence.

A very elegant writer, *On the Sublime and Beautiful*, concludes his account of the paſſions thus: "The more accurately we ſearch into the human mind, the ſtronger traces we every where find of *his wiſdom who made it*. If a diſcourſe on the parts of the human body may be conſidered as a hymn to the Creator, the uſe of the paſſions, which are the organs of the mind, cannot be barren of praiſe to him, nor unproductive to ourſelves of that noble and uncommon union of ſcience and admiration, which a contemplation of the work of infinite wiſdom alone can afford a rational mind, while referring to him whatever we find of right, or good, or fair in ourſelves, diſcovering his ſtrength and wiſdom even in our own weakneſs and imperfection, honouring them where we diſcover them clearly, and adoring their profundity, where we are loſt in our ſearch: we may thus be inquiſitive without impertinence, and elevated without pride. We may be admitted, if I dare ſay ſo, into the counſels of the Almighty, by a conſideration of his works. This elevation of mind ought to be the principal end of all our ſtudies, which, if they do not in ſome meaſure effect, are of very little ſervice to us."

With this view theſe Lectures were written; to open and exalt your minds, by giving you juſt views of the nature of your ſituation, both with reſpect to this world and that which is to come; and

and that while I was enlightening your understandings, and diſplaying the beauties and glories with which you are environed, I might alſo incline your wills to the purſuit and practice of goodneſs, render you friends to religion, and lead you to love it's principles, adore it's author, and practiſe it's precepts.

While you are taking leſſons from Nature, and examining the wonderful and variegated phenomena ſhe preſents to your eyes, ſhall we neglect to ſhew that ſhe continually leads to the *true*, the *beautiful*, and the *good*—to the *ſupreme Being*, the ſource of all *truth*, the fountain of all *good*.

Wiſe and good men have always admitted the alliance between philoſophy and divinity, and have pronounced that nature was but half-ſtudied, till it enabled us to contemplate the great objects of religion with ſuperior light.

But, as paradoxical writers have affirmed, that infidelity would gain ground as philoſophy advanced; and as we have ſeen Voltaire turn the little philoſophy he was maſter of to the diſadvantage of religion, and endeavour, from his mole-hill of ſcience, to diſcredit Chriſtian truth, and bring faith and virtue into contempt, it is neceſſary to ſhew, that from true philoſophy and a right uſe of reaſon our religion has nothing to apprehend; that the more carefully and candidly they are ſtudied, the more conſpicuous will it's truth and beauty appear; and that no man can be made averſe to the word of God, by admiring his works, or raiſe objections againſt his truth, from the ſtudy of his power and wiſdom.

Religion ever had, and always muſt have, the character of it's author viſibly ſtamped upon it; and nothing can be found therein that is not infinitely kind and infinitely wiſe. The great aim of God in eſtabliſhing it is, to advance the happineſs

of man, and to advance it in a method consonant to those principles he has implanted in him.

Let no one then persuade you that an attention to the duties of religion is a sign of a poor and mean spirit, and fit only for the ignorant and superstitious. For religion, which is the habitual exercise of your best affections towards God, and towards man for his sake, is the noblest disposition of *the greatest and the noblest minds*, the foundation of all wisdom, the path to every thing desirable and good. And those who conceive it receives any advantage from ignorance, are neither acquainted with the nature of religion, the nature of God, nor the principles of their own nature: for *happiness*, which we are all in search of, consists in a certain *state* or *habit*, and in a certain *affection* and *disposition* of the soul; and whatever places the soul in this state, or produces this habit; whatever contributes to bring it into this state, or to maintain it therein; whatever disposes the soul to acquire this habit, or advance it's progress towards it; every such thing is to be ranked in the number of *a man's greatest goods*. Now, it is self-evident, that nothing but the cultivation and practice of every religious virtue can put you in possession of this state, and render you truly happy.

You will find no object so worthy of your utmost attention as your Creator; nothing that will advance your attainment of this glorious knowledge so much as a study of yourself by the light of revelation. Wisdom and happiness are one, to be truly wise is to be really happy: to be really happy, you must unite the love of God and man.

"The greatest men of the heathen world, Plato, Pythagoras, Socrates, Epictetus, Marcus Antoninus, &c. owed all their greatness to a spirit of devotion. They

They were full of God. Their wiſdom and deep contemplations only tended to deliver men from the vanity of the world, the ſlavery of bodily paſſions, that they might act as ſpirits that came from God, and were to return to him.

"There is nothing, therefore, that will raiſe you ſo much above vulgar minds, nothing that can render you truly *wiſe*, *great*, and *noble*, but rightly to know and worſhip your God and Saviour, who is the ſupport and life of all ſpirits, whether in heaven or on earth."

Believe not thoſe who deſcribe religion as ſevere, paint her aſpect as forbidding, or repreſent her determinations as gloomy. She inculcates no ſeverity of manners; meekneſs and humility are her fundamental graces: ſhe grants you without reſtraint every rational pleaſure, every enjoyment that can be productive of good to others, or that you can look back upon with ſatisfaction yourſelves. She denies you only what would be detrimental to ſociety, and would entail pain, miſery, or diſeaſe on yourſelves.

The means of happineſs are placed in all our hands, but religion alone can enable you to uſe them properly. She is to the *mind* what *health* is to the body; not only the firſt and greateſt of all pleaſures, but the only medium through which others can be enjoyed. Her pleaſures are deeply rooted in the heart, founded on the reaſon of things, permanent as the immortal ſpirit where it dwelleth, and durable as the eternal object whereon it is fixed. If you, after a weary and diligent flight in ſearch of happineſs, can find a ſurer ground on which to reſt the ſole of your foot, there let it reſt. If you can find a better and firmer foundation on which to build your happineſs, there let it be fixed.

The destructive ideas of the atheists of France, who, under the veil of philosophy, have long concealed their atrocious designs on the peace and happiness of mankind, render it more necessary to press these subjects on your minds; for who without detestation can have seen their attempts, or have looked without horror on their schemes. —A very slender consideration will prove to you, that all men would be politically happy, if no one endeavoured to injure another. The restraints of civil society aim at accomplishing this object, but vain will be the endeavours of *government*, unless *each individual* will co-operate to the great purpose, by restraining his own malignant passions. No principles that do not inculcate this *self-denial*, can ever promote *the happiness of man*, nor can any principles furnish motives for the law of *self-restraint*, but those derived from *religion*. Thus may you obtain other proofs of it's weight and importance. Thus you may be enabled to judge of the writings and principles of those who wish to deprive you of happiness *hereafter*, and rule over you *here* under the pretext of *liberty*. No real repose can be obtained in society, but that which is produced by *a religious morality*, by which alone each individual can contribute to, and enjoy the happiness of others, both past, present, and future.

APPENDIX

APPENDIX TO LECTURE III.

OF THE IMPROVEMENTS ON THE AIR-PUMP.*

TO no invention is natural philoſophy more indebted than to that of the AIR-PUMP: even in it's original imperfect ſtate it was the occaſion of many important diſcoveries; theſe have been ſince multiplied and extended to a degree of which it's firſt contrivers could have no idea, and ſcience ſeems to have advanced, in proportion as this inſtrument has been improved.

The air-pumps in moſt general uſe are made either with ſtop-cocks or with valves, to prevent the return of the air into the receiver, out of which it had been exhauſted. The pumps with ſtop-cocks, when well made and newly put together, are generally found to rarify the air to a greater degree than thoſe which are made with valves; but after being ſome time uſed, they become leſs accurate than the valves. The valves are alſo imperfect; for the external air, preſſing upon that in the piſton, prevents it's riſing when the elaſtic force of the air in the receiver under exhauſtion is much diminiſhed.

This inconvenience was entirely removed by a contrivance which cut off the communication between the inſide of the barrels and the outſide air, ſome defects, however remained; it will therefore be neceſſary to dwell a little longer on this conſtruction, and to compare it more particularly with thoſe uſually made.

 I have

* Cuthbertſon's Deſcription of an improved Air-Pump. Philoſ. Tranſ. for 1751 and 1752, and 1783. American Tranſ. vol. 1. Boſton, 1785.

I have already obſerved to you, that the valve at the bottom of an air-pump is opened by the ſpring of the air acting againſt it underneath, when the weight of the air is removed from the top of the valve, by raiſing the piſton in the barrel.

In order to remove this reſiſtance from the top, the piſton ſhould be made to fit exactly to the valve plate, when put down upon it; for if there be any ſpace between the bottom of the piſton and valve, it will retain part of the air; and this air (even when the piſton is at the higheſt) will, by it's expanſion, in ſome meaſure, obſtruct the opening of the valve.

When the air in the receiver, or underneath the valve, is rarified to an equal degree with the air contained in the barrel, (the piſton being drawn up to the higheſt,) the valve cannot riſe, becauſe the reſiſtance above is equal to the power below.

The reſiſtance from this air contained in the barrel againſt the valve at the bottom will be uniformly the ſame, while the piſton is at the ſame diſtance from it, becauſe the atmoſphere is continually preſſing on the piſton valve, and will prevent the air below paſſing through it, while this air is rarer than the atmoſphere; and when the piſton is put down to the bottom of the barrel, it will not eſcape through the piſton, but only be compreſſed into the vacancy between the bottom of the piſton, and the valve plate at the bottom of the barrel, and be of equal denſity with the atmoſphere.

Beſides the reſiſtance ariſing from the retained air, you are alſo to conſider that the weight of the valve, its tenacity, its coheſion to the plate occaſioned by the oil, and its being ſtretched tight over the hole, all increaſe the obſtruction, eſpecially when

when the ſpring of the air under the valve is much weakened by rarifaction.

If the reſiſtance ariſing from theſe cauſes be taken into the account, the denſity of the air in the barrel, when compreſſed in the above-mentioned vacancy, will be as much greater than the denſity of the atmoſphere above the piſton, as is added thereto by this reſiſtance, for this obſtruction belongs to both valves. And ſo alſo when this retained air is expanded, ſay one hundred times, by raiſing the piſton, the air in the receiver cannot be rarified to the ſame degree, becauſe of this reſiſtance of the valve at the bottom of the barrel.

Theſe difficulties Mr. Smeaton endeavoured to remove, by expoſing a much larger ſurface of the lower valve to the air underneath, by placing it on a kind of grate, which leſſened the coheſion, while from the ſize more power could apply to open the valve.

He, in a great meaſure, removed the difficulty ariſing from the air retained in the barrel, by making the piſton fit more nicely to the bottom, and by *taking the weight of the atmoſphere off the piſton*; this allowed the piſton valve to open more eaſily, ſo that much more of the air could paſs through it.

The weight of the atmoſphere was removed from the piſton, by cloſing the top of the barrel with a plate, on which he fixed a collar of leathers; through this the cylindrical part of the piſton-rod moves air-tight. And the air, having paſſed through the piſton, is forced out of the barrel through a hole in the top plate, over which is a valve to prevent the return of air when the piſton deſcends, which is made to fit as exactly to the top as to the bottom of the barrel, to exclude the air more effectually.

This being underſtood you will be able to ſee more clearly the value of the improvements made on

on the air-pump, by the Rev. Mr. Prince, of the Maſſachuſet's State, who, judging from attempts already made, in order to leſſen the imperfection of the valves, that if he could take away the valves entirely, the rarifaction might be carried on ſtill farther; he conſtructed a pump upon that plan. To effect this, he removed the lower valve, and opened the bottom of the barrel into a ciſtern on which it is placed, and which has a free communication with the receiver; for the valve on the upper plate, at the top of the barrel, (which is conſtructed like Mr. Smeaton's,) makes it unneceſſary there ſhould be any at the bottom in order to rarify the air in the receiver.

The ciſtern was made deep enough to allow the piſton to deſcend below the bottom of the barrel. If the piſton be ſolid, that is without a valve, when it enters the barrel and riſes to the top plate (which is made air-tight by a collar of leathers,) it forces out all above it; and as the air cannot return into the barrel on account of the valve on the top plate, when the piſton deſcends there will be a vacuum between it and the plate, every thing being ſuppoſed perfect.

But in working the pump, the piſton only deſcends below a hole in the ſide of the barrel, near the bottom, which opens a free communication between the barrel, ciſtern, and receiver. Through this hole the air ruſhes from the ciſtern into the exhauſted barrel, when the piſton has been dropped below it; and, by it's next aſcent, this air is forced out as the other was before. If the capacity of the receiver, ciſtern, pipes, &c. below the bottom of the barrel, taken together, be equal to the capacity of the barrel, half the remaining air will be expelled by every ſtroke.

But as working the pumps with a ſolid piſton would be laborious, on account of the reſiſtance it would

would meet with in it's descent from the air beneath, (though this would be lessened every stroke as the air becomes more rarified,) Mr. Prince pierced a hole through the piston, and placed a valve over it, which opened with sufficient ease to prevent any labour in working the pump, by allowing the air to pass through the piston in it's descent.

But the escape of the air does not necessarily depend upon a passage through the piston in order to get into the barrel; for, when the air becomes so weak from its rarifaction that it cannot open this valve, it will still get into the barrel when the communication therewith is opened by the hole at the bottom. The piston will therefore descend as easily as any other, while at the same time it's valve does not impede the rarifaction. Thus the valves, which Mr. Smeaton only made to open with more ease, are rendered unnecessary towards rarifying the air, while that at the bottom of the barrel is entirely removed, that on the top plate being the only one necessary for rarifying the air.

Having thus set aside the valve, Mr. Prince's next attempt was to expel the air more perfectly out of the barrel than by Mr. Smeaton's pump; and this he effected by making a better vacuum between the piston and the top plate, to allow more air to expand itself into the barrel from the receiver. Removing the pressure of the atmosphere from the valve on the pump-plate, by means of a small pump of the same construction with the large one, which he denominates the valve-pump; and the air will evacuate itself so much the more, as the valve of the piston opens with more ease, which is here the case.

For the further peculiarities in this construction, I must refer you to the original paper of the author, as what I have already related is fully sufficient to render you master of the principles on which it acts.

On

On the successive degrees in which the air is rarified by a common air-pump.

AS you are now sufficiently acquainted with the fabric and contrivance of the pump, so as to understand in general the manner of its operation, I shall now enter on some particulars which have not been hitherto considered.

It may perhaps on a first view not seem improbable that an equal evacuation is made at each stroke of the pump, and consequently that the receiver may, after a certain number of strokes, be perfectly exhausted; for it must be allowed, if an equal quantity of air is taken away at every stroke, that the receiver will in time be perfectly exhausted, how small soever those equal quantities which are continually taken away may be supposed to be. Thus, if the air which goes out of the receiver at each turn of the pump be but the hundredth part of what was at first included in the receiver, it is certain that a total evacuation will be made after an hundred turns. That things are thus, may at first view, I say, seem not improbable; but if we consider the matter more nearly, we shall find it to be far otherwise.

What I shall endeavour to make out to you is this; that the quantities exhausted at every stroke are not equal, but are perpetually diminished, and grow less always so long as you continue to work the pump: that no receiver can ever be perfectly and entirely evacuated, how long time soever you employ for that purpose, notwithstanding that the engine be absolutely free from all defects, and in the greatest perfection which can be imagined. It may appear to be a paradox, that a certain quantity of the air in the receiver should be removed at every

every turn of the pump, and yet that the whole can never be taken away; but I hope I ſhall eaſily ſatisfy that it is not a miſtake. Laſtly, that I may not ſeem too much to depreciate the value of our engine, I have this further to ſay for it, that though it be impoſſible by its means to procure a perfect vacuum, yet you may approach as near to it as you pleaſe. By a perfect vacuum here, I mean in reſpect of *air only, not an abſolute vacuity in reſpect of every thing which is material; for, not to mention what other ſubtile bodies may poſſibly be lodged in our receivers, it is matter of fact, that the rays of light are not excluded from thence.*

In order to make out theſe aſſertions, I ſhall in the firſt place lay down this rule—That the quantity of air which is drawn from the receiver at each ſtroke of the pump, bears the ſame proportion to the quantity of air in the receiver immediately before that ſtroke, as the capacity of the barrel into which the air paſſes from the receiver does to the capacity of the ſame barrel and the capacity of the receiver taken together. You may remember that in each barrel there are two valves, whereof the lower is placed at the bottom of the barrel, and the upper is fixed upon the piſton. Now the hollow ſpace which lies betwixt theſe valves, when the piſton is raiſed as high as it can go, is what I call the capacity of the barrel; for the other part of the cavity of the barrel, which is above the piſton and the upper valve, is of no uſe in evacuating the receiver, and therefore ought not here to be conſidered. Upon a like account, by the capacity of the receiver, I mean not only the ſpace immediately contained under the receiver, but alſo all thoſe other hollow ſpaces which communicate with it, as far as to the lower valves: ſuch you may remember are the cavity of the pipe which conveys the air to the barrels,

 and

and the cavity in the upper part of the gage above the quickſilver. Theſe additional ſpaces are very ſmall and inconſiderable: yet if we would be exact, they alſo muſt be taken into the account and looked upon as parts of the receiver. Now, to underſtand the truth of this rule, we muſt obſerve, that, as the piſton is moved upwards from the bottom of the barrel, it would leave a void ſpace behind it, but this effect is prevented by the ruſhing in of air from the receiver. The air, you know, by it's elaſticity, is always endeavouring to expand itſelf into larger dimenſions, and it is by this endeavour that it opens the lower valve, and paſſes into the hollow part of the barrel as the piſton gives way to it; and this it will continue to do, till it comes to have the ſame denſity in the barrel as in the receiver: for, ſhould its denſity in the barrel be leſs than in the receiver, it's elaſtic force, which is proportionable to its denſity, would be leſs alſo, and therefore it muſt ſtill give way to the air in the receiver, till at length the denſities become the ſame. The air then, which immediately before this ſtroke of the pump (by which the ſucker is raiſed) was contained in the receiver only, is now uniformly diffuſed into the receiver and the barrel; whence it appears that the quantity of air in the barrel is to the quantity of air in the barrel and receiver together, as the capacity of the barrel is to the capacity of the barrel and receiver together. But the air in the barrel is that which is excluded from the receiver by this ſtroke of the pump, and the air in the barrel and receiver together is what was in the receiver immediately before the ſtroke. Therefore the truth of the rule is very evident, that the quantity of air which is drawn from the receiver at each ſtroke of the pump, bears the ſame proportion to the quantity of air in the receiver immediately before that ſtroke,

 as

as the capacity of the barrel into which the air paſſes from the receiver does to the capacity of the ſame barrel and the capacity of the receiver taken together. To illuſtrate this further by an example, let us ſuppoſe the capacity of the receiver to be twice as great as the capacity of the barrel; then will the capacity of the barrel be to the capacity of the barrel and receiver together as one to three, and the quantity of air exhauſted at each turn of the pump is to the quantity of air which was in the receiver immediately before that turn, in the ſame proportion. So that by the firſt ſtroke of the pump, a third part of the air in the receiver is taken away; by the ſecond ſtroke, a third part of the remaining air is taken away; by the third ſtroke, a third part of the next remainder is exhauſted; by the fourth, a third part of the next; and ſo on continually; the quantity of air evacuated at each ſtroke diminiſhing in the ſame proportion with the quantity of air remaining in the receiver immediately before that ſtroke: for it is very evident, that the third part, or any other determinate part, of any quantity, muſt needs be diminiſhed in the ſame proportion with the whole quantity itſelf. And this may ſuffice for the proof of what I aſſerted in the firſt place, viz. that the quantities exhauſted at every ſtroke are not equal, but are perpetually diminiſhed.

I ſhall now proceed to ſhew that the air remaining in the receiver, after every ſtroke, is diminiſhed in a geometrical progreſſion. It has been proved that the air remaining in the receiver, after each ſtroke of the pump, is to the air which was in the receiver immediately before that ſtroke, as the capacity of the receiver is to the capacity of the barrel and receiver taken together; or, in other words, that the quantity of air in the receiver, by each ſtroke of the pump, is diminiſhed in the proportion

proportion of the capacity of the receiver to the capacity of the barrel and receiver taken together: each remainder is therefore evermore leſs than the preceding remainder in the ſame given *ratio*; that is to ſay, theſe remainders are in a geometrical progreſſion continually decreaſing. Let us return again to our former example which may afford a ſomewhat different light into this matter. The quantity exhauſted at the firſt turn, you remember, was a third part of the air in the receiver, and therefore the remainder will be two-thirds of the ſame; and for the like reaſon the remainder after the ſecond turn will be two-thirds of the foregoing remainder, and ſo on continually, the decreaſe being always made in the ſame proportion of two to three; conſequently the decreaſing quantities themſelves are in a geometrical progreſſion. It was before proved that the quantities exhauſted at every turn did decreaſe in the ſame proportion with theſe remainders; therefore the quantities exhauſted at every turn are alſo in a geometrical progreſſion. Let it then be remembered, that the evacuations and the remainders do both of them decreaſe in the ſame geometrical progreſſion. If the remainders do decreaſe in a geometrical progreſſion, it is certain you may, by continuing the agitations of the pump, render them as ſmall as you pleaſe; that is to ſay, you may approach as near as you pleaſe to a perfect vacuum. But notwithſtanding this, you can never entirely take away the remainder. If it be ſaid that you may, I prove the contrary thus—Before the laſt turn of the pump, which is ſaid wholly to take away the remainder, it muſt be confeſſed there was a remainder; this remainder, by that laſt turn of the pump, will only be diminiſhed in a certain proportion, as has been before proved; therefore it was falſely ſaid to be totally taken away.

There

There are three kinds of gages used with the air-pump to measure the degrees of exhaustion; the first, called the *long barometer gage;* the second, the *short barometer gage;* the third, the *pear gage*, or manometer. The two first shew the elasticity of the fluid in the receiver, but do not determine whether it be permanently elastic air; the third shews the density of the air left in the receiver, without regarding such vapours as may assume an elastic form in the vacuum, *fig.* 11, *pl.* 1. The short gage is often made in the form of an inverted syphon, with one leg open, and the other hermetically sealed; this is sometimes called *Mairan's gage*, *fig.* 12, *pl.* 1.

It may not be improper in this place to say something concerning the gradual ascent of the quicksilver in the long barometer gage, upon which we have made some experiments. You have observed, that as we continue to pump, the quicksilver continues to ascend, approaching always more and more to the standard altitude in the weather-glass, which you know is about twenty-nine and a half inches, being a little under or over according to the variety of seasons. What I shall now endeavour to make out to you is this: that the defect of the height of the quicksilver in the gage from the standard altitude, is always proportionable to the quantity of air which remains in the receiver: that the altitude itself of the quicksilver in the gage is proportionable to the quantity of air which has been exhausted from the receiver; that the ascent of the quicksilver, upon every turn of the pump, is proportionable to the quantity evacuated by each turn.

In order to understand these assertions, you are to consider that the whole pressure of the atmosphere upon the cistern of the gage is equivalent to, and may be balanced by, a column of quick-

ſilver of the ſtandard altitude. Therefore, when in the gage, the quickſilver has not yet arrived to the ſtandard altitude, it is certain the defect of quickſilver is ſupplied by ſome other equal force, and that force is the elaſtic power of the air yet remaining in the receiver, which, communicating (as you remember) with the upper part of the gage, hinders the quickſilver from aſcending, as it would otherwiſe do, to the ſtandard altitude. The elaſticity of the air in the receiver is then equivalent to the weight of the deficient quickſilver: but the weight of that deficient quickſilver is proportionable to the ſpace it ſhould poſſeſs, or to the defect of the height of the quickſilver in the gage from the ſtandard height: therefore the elaſticity of the remaining air is alſo proportionable to the ſame defect. And ſince it was formerly proved, that the denſity of any portion of air is always proportionable to its elaſticity, and the quantity in this caſe is proportionable to the denſity, it follows, that the quantity of air remaining in the receiver is proportionable to the defect of the quickſilver in the gage from it's ſtandard altitude, which was the firſt thing to be proved. Hence it follows, that the quantity of air which was at firſt in the receiver before you began to pump, is proportionable to the whole ſtandard altitude, and conſequently the difference of this air which was at firſt in the receiver, and that which remains after any certain number of turns, that is, the quantity of air exhauſted, is proportionable to the difference of the ſtandard altitude, and the before-mentioned defect, that is, to the altitude of the quickſilver in the gage after that number of turns; which was the ſecond thing to be proved. And from hence it follows, that the quantity of air exhauſted at every turn of the pump, is proportionable to the aſcent of the quickſilver upon each

each turn, which was the laſt thing to be made out. And theſe concluſions do very well agree with the experiments, which ſhewed us the quantity of air that was exhauſted by the quantity of water which afterwards ſupplied the vacant place of that air in our receiver. Let it then be remembered, that the quantity exhauſted at each turn is proportionable to the aſcent of the quickſilver upon that turn; that the whole quantity exhauſted, from the time you began to pump, is proportionable to the whole altitude of the quickſilver; that the quantity remaining in the receiver is proportionable to the defect of that altitude from the ſtandard. To come now to the application of the other experiments which we made this day: we found, you remember, that the ſeveral aſcents of the quickſilver in the gage, upon every turn of the pump, were diminiſhed in a geometrical progreſſion; and it has juſt now been proved, that the quantities of air exhauſted at each turn, are proportionable to thoſe aſcents. Therefore, we may ſafely conclude, from experiment alſo, what we before collected by a train of reaſoning; that the quantities of air exhauſted at every turn of the pump are diminiſhed continually in a geometrical progreſſion. Furthermore, ſince thoſe aſcents are the differences of the defects from the ſtandard altitude, upon every ſucceſſive turn of the pump; it follows, that the defects alſo are in the ſame decreaſing geometrical progreſſion. For it is a general theorem, that all quantities, whoſe differences are in a geometrical progreſſion, (ſo long as the quantities continue to have any magnitude,) are themſelves alſo in the ſame geometrical progreſſion. The defects being then in a decreaſing geometrical progreſſion, and the quantities of air remaining in the receiver being proportionable, (as was lately proved) to the defects; it follows from the ſame

experiments, that the quantities of air which remain in the receiver after every turn of the pump, do decreaſe in a geometrical progreſſion; which was the other thing concluded alſo by a train of reaſoning.

The ſhort gage, (*fig.* 2. *pl.* 2.) conſiſts of a tube ſix or 8 inches long, filled with mercury, and inverted in a ſmall baſon thereof, in the ſame manner as the common barometer; in this the mercury does not begin to deſcend till about three-fourths of the air is exhauſted, after which it begins to ſhew the degree of exhauſtion, which is in proportion as the height of its column to the height of the mercury in the common barometer.

The pear-gage, (*fig.* 11. *pl.* 1.) would be the moſt accurate of any, if it were not that moſt fluid ſubſtances, as has been fully proved by *Mr. Nairne*, aſſume an elaſtic form; when the preſſure of the atmoſphere is removed, it therefore ſeldom indicates the elaſticity or actual preſſure of the fluid remaining in the receiver.

By this gage, Mr. Nairne diſcovered that ſeveral ſubſtances, when placed under a receiver, will, during the time of exhauſtion, emit a kind of vapour or damp, which, by it's expanſion, will drive and force out moſt of the permanent air; but that when the preſſure of the air is reſtored, this vapour loſes it's expanſibility, and is condenſed into it's former ſtate.

Hence this gage will ſometimes indicate that all the permanent air is exhauſted out of the receiver except about $\frac{1}{10.000}$ part, when other gages do not ſhew a degree of exhauſtion of more than 200 times, ſometimes much leſs.

The pear-gage, (*fig.* 11. *pl.* 1,) conſiſts of a bulb of glaſs, ſomething in the ſhape of a pear, and ſufficient to hold about half a pound of quickſilver: it is open at one end, and at the other is a tube,

tube, hermetically closed at the top. By the help of a nice pair of scales you find what proportion of weight a column of quicksilver, of a certain length, contained in the tube, bears to that which filled the whole vessel: by these means you will be enabled to mark divisions upon the tube answering to a 1000th part of the whole capacity; which, being about one-tenth of an inch each, may, by estimation, be easily subdivided into smaller parts. This gage, during the exhausting of the receiver, is suspended therein by a slip wire. When the pump is worked as much as shall be thought necessary, the gage is pushed down till the open end is immerged in a cistern of quicksilver placed underneath; the air being then let in, the quicksilver will be driven into the gage till the air remaining in it becomes of the same density with the external; and as the air always takes the highest place, the tube being uppermost, the expansion will be determined by the number of divisions occupied by the air at the top.

Mr. Nairne put the short barometer-gage, and the pear-gage, with a glass cup having a wooden foot, both together under the receiver, which receiver was placed on a leather soaked in oil and tallow, on the plate of the pump; the pump was then worked for ten minutes, and the quicksilver was brought down in the short barometer-gage to about one-tenth of an inch of the surface of the quicksilver in the cistern, and rose in the long barometer-gage to within one-tenth of an inch of the height of the quicksilver in a standard barometer, which was at that time at thirty inches; by which it appeared, that the pressure on the surface of the quicksilver in the cistern, and in the tube of the long barometer-gage, was diminished to about a 300th part: the pear-gage being now pushed down till it's open end was immersed un-

 der

der the ſurface of the quickſilver in the cup, the air was then let in, and the pump appeared by that gage to have exhauſted all but a 6,000th part of the air; or, in other words, the degree of exhauſtion by this gage appeared to be ſix thouſand times.

Mr. Nairne made many other experiments, all manifeſting a conſiderable diſagreement between the pear and other gages. Theſe differences Mr. Cavendiſh accounted for in the following manner: "It appeared," he ſaid, "from ſome experiments, "that water, whenever the preſſure of the at- "moſphere on it is diminiſhed to a certain degree, "is immediately turned into vapour, and is as "immediately turned back again into water on "reſtoring the preſſure. This degree of preſſure "is different according to the heat of the water: "when the heat is 72° of Fahrenheit's ſcale, it "turns into vapour as ſoon as the preſſure is no "greater than that of three quarters of an inch "of quickſilver, or about one-fortieth of the "uſual preſſure of the atmoſphere; but when the "heat is only 41°, the preſſure muſt be reduced "to that of a quarter of an inch of quickſilver, "before the water turns into vapour. It is true, "that water expoſed to the open air will evaporate "at any heat, and with any preſſure of the at- "moſphere; but that evaporation is entirely "owing to the action of the air upon it: whereas "the evaporation here ſpoken of, is performed "without any aſſiſtance from the air. Hence it "follows, that when the receiver is exhauſted to "the above-mentioned degree, the moiſture ad- "hering to the different parts of the machine "will turn into vapour and ſupply the place of "the air, which is continually drawn away by the "working of the pump, ſo that the fluid in the "pear-gage, as well as that in the receiver, will "conſiſt in good meaſure of vapour. Now let- "ting

"ting the air into the receiver, all the vapour "within the pear-gage will be reduced to water, "and only the real air will remain uncondensed; "consequently the pear-gage shews only how "much real air is left in the receiver, and not how "much the pressure or spring of the included "fluid is diminished; whereas the common gages "shew how much the pressure of the included "fluid is diminished, and that equally, whether it "consist of air or of vapour."

Mr. Cavendish having explained so satisfactorily the cause of the disagreement between the two gages, it appeared that if moisture were avoided as much as possible, the two gages would nearly agree, which was proved by a variety of experiments, from which the following are selected:

The plate of the pump being made as clean and as dry as possible, there was then put on it the before-mentioned short barometer-gage, also the pear-gage, with a cistern entirely of glass, which held the quicksilver; they were then covered with a receiver, round the outside of which was laid a cement, which perfectly excluded the outward air; every part before it was put under the receiver, as well as the receiver itself, being made as clean and as free from moisture as possible.* The pump was then worked for ten minutes, and the barometer-gages indicated a degree of exhaustion nearly 600: the air was then let into the receiver, the pear-gage indicated a degree of exhaustion, but very little more than 600 also. The near agreement of the pear-gage with the barometer-gages,

* It may be proper here to take notice, that the pump in every experiment hereafter-mentioned was worked ten minutes, and the same receiver continued cemented to the pump-plate, except where it is otherwise mentioned. The top part of this receiver was made to open, in order to put in different things.

in this laſt experiment, in which moiſture was excluded as much as poſſible, ſeemed to prove beyond a doubt, that their diſagreeing muſt have been owing (as Mr. Cavendiſh ſuppoſed) to the moiſture which in them had not been ſo carefully excluded. But, as there might ariſe a vapour from ſome moiſture that might be contained in the leather ſoaked in oil and tallow, or in the wooden foot which was cemented to the glaſs cup, the following experiments were tried:

A piece of leather dreſſed in allum, known by the name of white ſheep-ſkin, of about four inches diameter, which had been ſoaked in oil and tallow about a year ago (ſuch as was uſed to place the receiver on in the firſt and ſecond experiments) was put into the receiver; the pump was then worked, and the barometer-gage indicated a degree of exhauſtion of nearly 300; but on the admiſſion of the air the pear-gage indicated a degree of exhauſtion of 4,000.

The piece of leather being taken out, the pump was then worked, and the degree of exhauſtion appeared by both the barometer and pear-gages to be about 600, as in the third experiment.

A cylinder, made of a piece of box wood, which had been kept for more than a year, one inch in diameter, and three inches in length, was put into the receiver (this piece of wood was of the ſame kind as that which was cemented to the foot of the glaſs cup uſed in the firſt and ſecond experiments,) the pump was then worked, and the degree of exhauſtion appeared by the barometer-gage to be 300, but by the pear-gage 16,000.

Theſe experiments were often repeated, but the reſult was ſeldom the ſame. When leather ſoaked in oil and tallow has been put into the receiver, the pear-gage has ſometimes indicated a degree of exhauſtion of 20,000, and ſometimes

it likewiſe differs very much
which may perhaps be owing
of heat and moiſture.
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Particular

Particular care ſhould be taken, after making any experiments, where vapour has been generated, to clear the pump of it, before any other experiments are attempted; for this fluid or vapour remains not only in the receiver, but alſo in the tubes and barrels of the pump, and will, when the air is again rarified, expand as before.

To clear the pump of this vapour, take a large receiver, and, wiping it as before directed, exhauſt it as far as poſſible. The expanſible vapour which remained in the barrels and the pipes will now be diffuſed through the receiver, and conſequently will be as much rarer than it was before, as the aggregate capacity of the receiver is larger than that of the pump and pipes. If the receiver be large, one exhauſtion will be ſufficient to clear the pump ſo far, that what remains can be of no conſequence. If the receiver be ſmall, the operation ſhould be repeated two or three times.

It may be proper to obſerve here, that for the beſt pumps, the plate and the edges of the receivers are ground ſo true, as not to require any leathers; but as ſetting the receivers dry upon the plate is apt to ſcratch and ſpoil it, you will find it always uſeful to ſpread a little hog's lard or tallow upon their edges. This prevents the edges of the receivers from damaging the plate, and does not emit any vapour.

LECTURE

LECTURE IV.

ON THE NATURE AND PROPERTIES OF AIR.

IN writing these Lectures, I have had four points in view. 1. To support and shew that there is a strict alliance between natural, moral, and sacred philosophy. To use the words of a man of the first abilities, "*The great Author of all things*, viewed in every possible relation to man, should ever be the object to which all our studies and inquiries converge, as the center of all truth, and the source of all being and perfection. Whatever has not an unvaried regard to him, deviates from it's true line and direction, and must lead to *error and mental depravation*;"* whereas a proper view of philosophy will shew you, "That whatever is *permanent* in outward nature—whatever is *immutably true* in *morals* or in *politicks*, oweth it's permanency and truth to the eternity and immutability of the divine cause of all things—the *Creator* of outward nature—the *Father* of all moral beings—the *Author* of all good government. That whatever is *demonstrable* in any of the *sciences*—whatever is *certain* in any of the arts dependent on those sciences, derives it's clearness in theory, and it's certainty in practice, from the self-evident principles of *mind*, whose fountain is the *Divine* essence."

Natural philosophy, in it's proper extent, sober use, and application, is a noble science; but to confine it to nature, matter, motion, and mechanism, excluding morality and theology, is to contract, to degrade, and debase it below the meanest occupation of life.

2. To

* Berrington's Immaterialism delineated.

2. To render this work a kind of natural and practical logic, that ſhall enable you to diſtinguiſh what is ſound and ſolid, from what is hollow and vain. To prevent an undue attachment to any ſyſtem, and to counteract the influence of names and authority, in a ſcience where free diſquiſition ſhould be allowed in it's full extent, and where candour and ſerenity ſhould always prevail.

Sorry I am to ſay, that philoſophy is ſtill too much governed by an intolerant ſpirit which obſtructs the advancement of ſcience, and obliges it to run in one narrow channel. And ſuch is the zeal of it's profeſſors, that they can ſeldom bear to have thoſe principles canvaſſed which they have adopted. Thus proving, that they are void of that ſpirit of inquiry and liberality, which, by exciting the mind to trace up effects to their cauſes, becomes the parent of diſcovery.

Happy ſhall I eſteem myſelf if theſe remarks ſhould lead you to a purer love of truth; and that, inſtead of inquiring who it is that writes, you would attend only to what is written, and learn to avoid the ſtrife of formal diſputation; or, as Bacon terms it, "The giddy agitation and whirlwind of argument, in which victory is more contended for than truth."

3. To point out to you the boundaries of human reaſon, and by ſhewing you how ſmall a way we penetrate into the nature of things, induce you to obſerve carefully and judge cautiouſly; engage you to proſecute your reſearches into nature, with a juſt conviction of the fallacy of your ſenſes, and the limited powers of your underſtanding; to diſcourage the vain deſire of accounting for all phenomena. Many phenomena in nature are unaccountable, and we muſt ſometimes be humble enough to admire what we cannot

not underſtand; as we ſurvey the ocean with pleaſure, though we cannot ſee the bottom of it.

Conſcious, therefore, of the fallibility which attends the beſt exertions of human reaſon; ſenſible of the darkneſs under which the *author* of all knowledge hath left ſome of it's moſt intereſting and important parts; and convinced that, as the ſearch after truth is your duty, and will conſtitute a great portion of your happineſs, you will always enter upon the taſk with humility, with diligence, with deſire, and all the beſt affections of the heart and underſtanding; with *hope*, and indeed with *fear*. For Error is open with a thouſand ways (whereas Truth has only one), and as an enemy in ambuſh, is prepared on all occaſions to turn you aſide from the direct and ſucceſsful road.*

You may be aſſured, that a philoſophy which makes human reaſon the meaſure of all things, inſtead of being founded on enlarged and ſuperior knowledge, ſtands on the narrow bottom of ignorance, and as it riſes in vanity, will increaſe in abſurdity.

4. To exhibit in a natural and eaſy manner (as we have already informed you) the principal and the moſt important of natural phenomena, to account for their cauſe, and to illuſtrate both by experiments.

It is to be hoped, that from the manner of treating theſe ſubjects, your judgment will receive an acceſſion of ſtrength and acuteneſs, which it may ſucceſsfully employ upon other objects and upon other occaſions.

Of Observation and Experiment.

As in a former lecture I ſhewed you the danger and impropriety of indulging conjecture and framing

* Tatham's Chart and Scale of Truth, p. 16.

framing hypotheses, I shall now on the other side, in pursuance of my design, commence this lecture with some remarks on the qualities that distinguish an observer of nature from a mere experimentalist, and point out the disadvantages that may accompany both observation and experiment, if either be too rigidly adhered to, or used independent of the other. Neither observation nor experiment are however to be neglected; they are two sisters which have a reciprocal necessity for each other's assistance.

The person who is best adapted by nature for making philosophical experiments, is generally the least fitted for drawing conclusions from them. There is a minuteness, an exactness required in an experimenter, which should not enter too much in his composition, who collects and applies the results arising from experimental inquiries.

The experimentalist is always discovering little differences, contriving methods to examine objects in ten thousand various ways, and to distinguish one thing from another by all possible minutiæ.

But the person who applies these experiments to the supporting or explaining any phenomena in nature, should be one who sees many things in one view, and comprehends the result of many effects springing from the same cause, and who overlooks the trifling differences from the accidents of time and place.

The *experimentalist* beholds all nature as particles of dust *disunited* from, and *uninfluenced* by one another; each a world of it's own, with properties and qualities peculiar to itself.

The *observer* sees all nature as *united*, as actuated and moving upon one common principle,

ciple, and all the parts as conſpiring to form one whole.

They are thus excellently diſcriminated by Lord Bacon: "The great and radical difference of capacities, as to philoſophy and the ſciences, lies here; that ſome are ſtronger and fitter to obſerve the differences of things; others their correſpondencies: for a ſteady and ſharp genius can fix it's contemplations, and dwell and faſten upon all the ſubtilty of differences, whilſt a ſublime and ready genius perceives and compares the ſmalleſt and moſt general agreements of things; but both kinds eaſily fall into exceſs, by graſping either at the dividing ſcale, or ſhadows of things. The former is ſo taken up with the particles of things, as almoſt to neglect their ſtructure, whilſt the other views their fabrication with ſuch aſtoniſhment, as not to enter into the ſimplicity of nature."

The material world is an immenſe body, compoſed of an infinite number of parts, ſo interwoven together as to unite in one common center. There is no inſulated fact in nature; they are all relative, having a double reference, as effects to their cauſes, and as cauſes to their effects. It is the buſineſs of philoſophy, to point out what apparently ſeparates the parts, and how they are connected, and to trace theſe connections to the principle of unity, which harmonizes and connects all the works of creation.

I will endeavour to render this important view of philoſophy more clear to you, by an extract from a work of the Rev. Mr. Jones; a writer in whom you will find great originality of ſentiment, expreſſed with energy and eaſe; in whoſe hands the moſt abſtruſe ſubjects are always rendered plain and clear. "Nature," ſays he, "is a ſyſtem of parts related, and every part ſhould be conſidered

considered under this relation,* without which, neither the nature nor design of it can be understood. Take the leg of a man, and consider it without any regard to the body it belongs to, it will then have no meaning in it, neither can he that examines it understand any thing more of it than it's substance and figure. But, if you consider the same member with it's relation to the body, then you discover with admiration, First, That it's vessels are supplied with the animating fluids of blood and spirits, which keep up the animal life in it. Secondly, That it's muscles are connected with the superior parts, from whence they derive their faculty of motion. Thirdly, That it is framed with due strength and exact proportion to the weight of the body, to preserve it in an erect position, and transport it from place to place. A limb, considered under these relations, is a wonderful subject, worthy to be admired by the anatomist and philosopher. But if you separate it from the body, it is dead, motionless, and useless. It is the same with any member of the frame of nature, even so much as a single atom, if taken independent of the rest. If we build a system on matter so independently considered, we shall raise such a world as never did, nor can exist; and which, after all our pains, will be as empty as it is arbitrary."

The experimentalist is apt to err in another point, and despise all systems, because he has neither compass of thought, nor extent of genius to see and embrace the idea of many consequences from one principle. He considers the author of a system

* Man, who is the servant and interpreter of nature, can act and understand no further than he has, either in operation or contemplation, observed of the method and order of nature.
Bacon, Nov. Org. Aph. 1.

ſyſtem as a viſionary in philoſophy, and one who is forming a new world of his own by the combination of incongruities: he, therefore, continuallyl abours at making new links, without ever forming them into a chain.

On the other hand, the ſyſtematic writer too often contemns the limited conceptions of the experimenter; he conſiders him like a worm that, creeping from one mole-hill to another, fancies each to be a diſtinct world, not ſeeing the common baſis which unites and ſupports them all. He fails, therefore, in framing his ſyſtem, from inattention to, and neglect of, experimental inquiries; and his building tumbles into ruin, as it wants thoſe pegs, which, though ſmall, are neceſſary to hold the whole together.

Having ſhewn you the danger that attends a too rigid attachment to the ſyſtematic or experimental mode of examining natural phenomena, I may proceed without fear to trace the further properties of air. This fugacious element is a rich, and almoſt inexhauſtible mine of knowledge, and your labours therein, if vigorouſly continued, will not fail of their reward.

OF THE AIR LODGED IN THE PORES OF DIFFERENT SUBSTANCES.

Four methods are uſed to extract air from the pores of thoſe bodies in which it is engaged. 1. By heating the bodies: 2. By cooling them: 3. By placing them under the vacuum of an air-pump: 4. By diſſolving them in ſome menſtruum.

1. By heating the ſubſtance we may extract the air that is contained in the pores thereof. The heat dilates the air ſo much, that it cannot be contained in the pores of any ſubſtance whoſe pores do not expand in the ſame proportion. Hence it is that you ſee it eſcape from meat and fruits while

roasting, from wood in burning, and from fluids in boiling. In the last instance you see the air which is rarified by the heat forming itself into bubbles, and traversing the fluid, in order to escape at it's surface.

2. When any substance is considerably cooled, it is condensed, and it's parts are brought closer together; it's pores are consequently lessened, and the air is forced out, as we force the water from a spunge, by compressing it.

3. The air which is lodged in the pores of any substance is disengaged when they are kept for some time in the vacuum of an air-pump: when the pressure of the atmosphere is removed by the air-pump, the air that was confined by that pressure to the bodies is let loose. This I shall illustrate by a variety of experiments on different substances.

4. The air may be disengaged from many substances by dissolving them in some menstruum; for the particles of the body that is dissolved, being disunited and subdivided by the dissolvant, the air is no longer confined, and therefore escapes with facility, as you see, when sugar is dissolving in water, and which I shall further illustrate in the course of this lecture.

The first experiment I shall shew you on this subject, will be with the clear water in this jar, which I shall place on the plate of the pump under a receiver: as soon as the air is a little exhausted, that which is contained in the water begins to expand and rise in bubbles, which pass through the water; they are small at first, but grow larger as they rise to the top of the water; and they will continue to rise, though more slowly, almost as long as the pump continues to work.

I shall now take away this jar, and place another with warm water under the receiver: when the

the preſſure of the air is taken off from the ſurface of the water, that which was contained therein unites in the form of bubbles; and, being acted on at the ſame time by the heat, the bubbles expand, and riſe with ſo much violence as to carry with them a thin portion of the fluid, and occaſion an appearance of ebullition on the water, ſimilar to that of boiling. When the fluids are of a more viſcous nature, as beer, ale, &c. the bubbles of air cannot burſt their caſes, and the fluid is formed into froth.

I place a jar of new ale under the receiver; as ſoon as I begin to work the pump the ale is filled with bubbles of air, which riſe copiouſly from every part; and, being coated with the viſcid particles of the ale, are prevented from burſting, and form on the ſurface thereof a white frothy head.

Here are a variety of ſubſtances that I have put into different jars with water, in order to place them under a receiver and exhauſt the water therefrom. The air lodged in the pores of theſe ſubſtances is as denſe as that of the ſurrounding atmoſphere, becauſe it ſuſtains, and is a counterballance to the preſſure thereof: as ſoon, however, as it is freed from this preſſure, it expands and eſcapes in great quantities from the pores in which it was confined. The water is uſed to render the eſcape of the air viſible; the air, as you have ſeen in the preceding experiments, aſſumes in it's paſſage the form of ſo many globules, a ſhape that any other fluid would aſſume where it is preſſed equally in every direction by another fluid. The water you uſe in theſe experiments ſhould be previouſly deprived of it's air, either by extracting it therefrom by an air-pump, or by boiling it, which will anſwer equally well.

Let us place this new-laid egg (that is in a jar

 covered

covered with water) under a receiver. As I work the pump the ſurface of the egg is covered with ſmall pearly bubbles of air, which ſeparate by degrees, and riſe to the ſurface of the water: at certain parts of the egg you perceive ſmall jets of air, which are formed by a continual ſucceſſion of theſe globules. The ſhell of an egg is porous, and in a few days a part of it's internal ſubſtance will evaporate; this is ſoon replaced by the air which ſurrounds it. The air contained in the egg will not eſcape ſo long as it is retained by the preſſure of the atmoſphere; but, when this preſſure is diminiſhed, then the internal air expands, and endeavours to paſs out, and thus diſcovers to us the pores in the ſhell. I ſhewed you in Lecture II. p. 42, the bubble of air at the large end of the egg, which bubble is one of the means uſed by nature, for bringing to perfection the chicken which is contained in embryo, in what we uſually call the treadle of the egg. The warmth communicated by the hen to the air in this bubble expands and puts it in motion; the air reciprocally preſſes on and communicates this motion to the egg, which, in ſome unknown manner, promotes the formation of the chicken. When the large end of the egg feels cold to the tongue, it is a proof that the egg is bad, that the air and milky ſubſtance thereof has eſcaped; in conſequence of which the egg becomes ſtale, putrid, or addled. *M. Reaumur*, the famous French naturaliſt, who ſeldom confined his ſpeculations to mere curioſity, has ſhewn, that by ſtopping up the pores of an egg with varniſh, or a ſlight covering of mutton ſuet, it may be preſerved perfectly freſh, and generally even fit for incubation five or ſix months after it has been laid.

This piece of wood is fixed to a weight, to keep it immerged in the water. I place it in a jar

jar under the receiver, and the air contained in the pores of the wood riſes in great quantities in fine ſtreams. You will find the ſame appearances from moſt ſubſtances, which you may try at your leiſure.

Here is a long piece of wood fixed to this piece of braſs; the braſs ſerves to cover the top of an open receiver: the long part of the piece of wood is immerged in the jar of water, (*fig.* 1, *pl.* 3,) while the upper part is expoſed to the open air. Place your thumb upon the top of the wood to cut off it's communication with the air: while I work the pump, you ſee the air contained in the pores of the wood ruſh through the water, as in the preceding experiment. Take off your thumb, and a vaſt ſtream of air flows in through the wood; by alternately taking away, and placing your thumb on the wood, you will alternately interrupt and permit the influx of air. This experiment ſhews that wood is pervious to air, and that the courſe of the air-veſſels is lengthwiſe.

This wooden cup is contrived to fit on the top of an open receiver: to the bottom of this cup a piece of wood is fitted (*fig.* 3, *pl.* 3.) I ſhall place the cup upon an open receiver, pour ſome quickſilver in it, and then exhauſt the air from the receiver. This being ſufficiently exhauſted, I pull out this plug, which lets the mercury come to the top of the piece of wood: the air you ſee forces itſelf through the pores thereof in ſuch fine ſtreams, as to form a ſhower of ſilver. Here is another cup furniſhed at bottom with a piece of buff-ſkin; by placing this on a receiver, and exhauſting the air as before, we procure another ſhower of mercury.

A piece of wood, conſidered according to it's length, is a collection or bundle of fibres in-

cluded within the bark, which ſerves as a common tegument: how ſmall ſoever theſe ligneous fibres may be, it is plain, from the preceding experiments, that there are interſtices between them, forming ſo many little canals or tubes through which the air and quickſilver paſſed.

It is owing to the poroſity of wood that it is liable to ſuch a variety of changes in it's volume or bulk. It is hence that wainſcotting in new buildings, and other joiners' work, which are not made of ſeaſoned ſtuff, often cleave with a great crack, and the joints loſe their exactneſs and ſolidity, and many other inſtances that will eaſily occur to your recollection; for all theſe effects ariſe from an increaſe of dimenſion by moiſture, or diminution by dryneſs. The experiment with a piece of buff-ſkin proves the extreme poroſity of the ſkin of animals: the quantity of matter which is thrown off from the human body, through the pores, is really ſurprizing. From the experiments of Sanctorius, and others, it appears, that of eight pounds of nouriſhment, which a man may have taken in twenty-four hours, inſenſible tranſpiration carries off five of them.

Here is a ſmall piece of wood cut ſmooth at each end, and immerged in a baſon of quickſilver; theſe I place under a receiver: on exhauſting the air, what is in the wood flies out of the pores paſſing through the mercury; on letting in the air again, it will fall with ſo much force upon the mercury, as to inject it through all the pores of the wood.

It is very probable that Ruiſch and Lieberkuhn made uſe of the preſſure of the atmoſphere for injecting fluid ſubſtances into the ſmaller veſſels of the human body, which has rendered ſome of their anatomical preparations ſo famous. The method they

they uſed is not known, but a Dr. Beuth is ſaid to have recovered it, and deſcribed the manner.*

There only remains to ſhew you that the air contained in the pores of different ſubſtances, may be diſengaged by diſſolving them in any menſtruum. The particles of the body to be diſſolved are diſunited and ſubdivided by the diſſolvant, and, the air being no longer confined, eſcapes with facility. The following experiment, which you may make any where, wants no apparatus but a tumbler of water and a deep diſh or baſon. As the experiment is of conſiderable importance, and the expert management thereof will be neceſſary when you come to conſider the nature of elaſtic fluids, I ſhall be very full thereon.

TO CONVEY AIR FROM ONE VESSEL TO ANOTHER.

Take any common glaſs receiver, vial, &c. fill it; put your finger, or open hand, on the mouth of it, ſo as not to let any water drop out, and invert it in a baſon of water; taking care that the mouth of the veſſel may be a little way below the ſurface of the water in the baſon; then ſlip away your hand, and the glaſs veſſel will, as you ſee, remain filled with the water. The weight of the atmoſphere preſſing upon the water in the baſon ſuſtains the water in the glaſs.

If I wiſhed to introduce ſome common air into this glaſs receiver filled with water, which ſtands in a deep veſſel of water, and preſerve it there detached from the general maſs, I proceed in the following manner: I take a ſmall veſſel, as this tea-cup, filled only with air, plunge it in the water of the baſon with the mouth downwards, which prevents the air from eſcaping; I then lift the glaſs from the bottom of the baſon, but not

* Poſitiones Phyſicæ.

ſo high as to come out of the water, bringing the cup under it, and then turning the mouth thereof downwards; the air is then forced out of it by the water, and aſcends to the upper part of the glaſs: being here confined by the water, you may keep it for any length of time. I now take away the cup, and ſet the glaſs down again on the bottom of the baſon. The method of thus conveying air and confining it being explained, I return to the experiment of ſhewing you the air diſengaged from ſubſtances by diſſolution. I firſt inverted this tumbler filled with water, as before directed: I put a piece of ſugar under the tumbler; and you ſee that, while it is diſſolving, bubbles of air are continually eſcaping from it; that they riſe from the top to the bottom of the jar, forcing the water out by their expanſion, and occupying the ſpace it quits. Thus have I ſhewn you that air, or ſome elaſtic fluid, is combined with, and forms a part of moſt ſubſtances; and may be diſengaged from them by one or other of the four methods juſt deſcribed.

This combination is an object worthy of admiration: you here find a large quantity of an elaſtic fluid, which, when diſengaged, occupies a ſpace many times larger than the ſubſtance from which it was extracted; yet, when combined therewith, is ſo far from tearing it to pieces, or even inflating it, that it appears in ſeveral inſtances to be neceſſary to it's coheſion and conſiſtency.

You have ſeen how ſoon water began to boil under the receiver of an air-pump, and that with a heat conſiderably leſs than is neceſſary for the ordinary production of ebullition. Indeed, without the preſſure of the atmoſphere, water would begin to boil with an ordinary heat, and would be transformed into a vapour, having it's particles

ſcattered indefinitely through the ſurrounding ſpace; an incumbent preſſure retards the production of vapour from thoſe ſubſtances, which yield it naturally while under leſs preſſure. Thus fermenting liquors yield a great quantity of elaſtic fluid under the uſual gravity of the atmoſphere; but the production thereof is conſiderably retarded in *condenſed air*. In like manner, fruits included in a receiver wherein the air is much condenſed, do not yield the ſame quantity of air they are wont to do in a leſs denſe medium.

In moſt caſes, if the ſubſtance from which the air has been extracted be expoſed again to the air, it regains ſooner or later what it had loſt. M. Mariotte proved this circumſtance by a very ſimple experiment, that you may repeat at your leiſure. For this purpoſe he extracted the air from a quantity of water; firſt, by boiling it, and afterwards keeping it ſome time in vacuo; he then filled a phial with this water, inverted it, placing the mouth under water; letting after this a bubble of air into it, according to the method explained. The bubble of air diminiſhed by degrees; in three days it was entirely vaniſhed; which proves that the air had been abſorbed, or had by ſome means inſinuated itſelf into the pores of the water.

OF THE AIR'S RESISTANCE.

The frame in my hand contains two mills, (*fig.* 4, *pl.* 3,) each of which has the ſame number of vanes (or ſails) of the ſame weight, and of the ſame length and breadth; with this difference, that in one the vanes are fixed edgewiſe, ſo as to cut the air with only a thin edge; the other breadthwiſe, meeting the air with the whole of it's ſurface. This ſpring preſſes ſtrongly againſt the two pins which are fixed to the naves of the mills: the piece which holds them preſſes equally againſt

against them, and thus gives them an equal impulse; when I set them in motion, they both begin to move with equal velocity: the one which meets the air with it's whole surface now moves slower than the other:—it has stopped; whereas the other still continues to move. We learn from this experiment, two things; 1st. That the air is a resisting medium; 2d. That it resists in proportion to the surface opposed to the air: for the mill which met and divided the air by the edge, having less air to remove, met with less resistance, and continued to move longer. Hence you see, that the same mass may meet with a different resistance in the same medium, according as it presents to it a greater or a lesser surface: hence also you will observe, that a waterman makes his oar act on the flat or broad side, when he uses the resistance of the water, to push him on; but that he lifts it out by the edge, that he may have less weight to surmount.

This experiment will receive additional force, if, at your leisure, you place your mills under the receiver of an air-pump, and when the air is exhausted put the mills in motion; the resisting medium being removed, they will both stop at the same time.

The experiment with the guinea and feather is one of the most celebrated among those made with the air-pump. This apparatus (*fig*. 10, *pl*. 3,) is so contrived as to let the guinea and feather fall at the same instant from the upper part of the receiver. The experiment may be repeated three times without taking off the apparatus, or exhausting the air afresh, the apparatus being so constructed as to let three guineas with their feathers, fall separately at three different times.

To make the effect more sensible, I shall let one guinea and feather fall while the air is in the receiver,

receiver, and you ſee the guinea reaches the bottom in an inſtant, but the feather deſcends gently, and with an indirect motion, to the bottom. I ſhall now exhauſt the receiver:—it is ready: look ſtedfaſtly at the bottom of the glaſs, and you will perceive the guinea and feather arriving at the ſame moment on the plate of the pump; proving that a light body falls juſt as faſt as a heavy one, in an unreſiſting medium.

Birds make uſe of the reſiſtance of the air to facilitate their motions, in the ſame manner as fiſhes make uſe of the water; by ſtriking the air with their wings they move forwards, their tail ſerving as a rudder to direct their courſe. The breaſt-bone, inſtead of being flat, riſes gradually from the ſpine, and terminates in a ſharp keel, which enables them to cut the air with greater facility: for the ſame purpoſe the heads of birds are proportionably ſmaller than thoſe of quadrupeds, and moſt of them terminate in light ſharp-pointed beaks. But, as the reſiſtance of the air is leſs than that of water, it muſt be ſtruck with more ſwiftneſs, or with a greater ſurface. Hence you find that thoſe birds which fly for a long time, and far, as ſwallows, &c. have generally ſmall bodies, many feathers, and large wings; while thoſe of a ſhorter, or leſs frequent flight, have commonly more fleſh and leſs wings in proportion. The latter, on obſervation, you will find beat their wings oftener than the others, in flying. Sparrows, chaffinches, goldfinches, linnets, &c. fly as it were by ſtarts, and do not ſupport themſelves long in the ſame direction. Their wings cannot raiſe and ſuſtain their bodies, but by a velocity in their motions, which they are obliged often to intermit: during the intermiſſion their weight gains upon them, and they loſe part of that elevation they had before obtained, ſo that

their

their flight is only a ſucceſſion of jerks and ſtarts. There are birds which ſupport themſelves for ſome time at the ſame height without ſeeming to move their wings; this is called planeing. There is little doubt but that they move their wings at this time; but then the vibrations thereof are ſo quick and ſo ſhort, that they cannot be perceived on account of the greatneſs of the diſtance. You will obſerve that theſe planeing birds are obliged from time to time to regain that height, by a flight in the common way, which they have inſenſibly loſt; and they then, by ſlower and more extenſive motions, repoſe as it were the muſcles that have been fatigued by theſe ſhort and frequent motions.

The reſiſtance of the air is a matter of great importance in the theory of gunnery, and allowance muſt be made for it in all it's calculations. And though every well-diſpoſed mind is deſirous of diſcouraging any improvements in the inſtruments of death, yet muſt the ſtudy of arms be continued and promoted till thoſe times come, *When nation ſhall not lift up ſword againſt nation, neither ſhall they learn war any more.* The nature of the reſiſtance of the air, and the method of inveſtigating it, are too abſtruſe and delicate to make a part of our lectures. I can only drop a hint or two to ſhew you the magnitude of it's effects; and hence the importance of ſome branches of ſcience, which might otherwiſe appear to you but of little uſe. Cannon or muſket-ſhot projected with velocities from 400 to 1600 feet in a ſecond, by their great velocity leave behind them, during their paſſage through the air, a partial vacuity: but when the velocity is equal to 1600 feet in a ſecond, the ſpace deſcribed by the ball, as it moves along, may be called an abſolute vacuum; conſequently, a ball moving with this velocity, muſt be reſiſted by the whole weight of the atmoſphere,

mosphere, exclusive of the effect derived from the air displaced. Mr. Robins found that this resistance on the ball of an iron 24-pounder, whose diameter is nearly 5½ inches, amounted to 540 pounds.

There is another circumstance which increases the resistance in bodies moving with great velocities; such, for instance, as 1800 or 2000 feet in a second: for the air before the ball being in this case condensed, exerts a force of elasticity against it, in proportion to the compression. This elastic force of the air, when exerted against bodies of small weight, but moving with considerable velocity, may become so great in proportion to the weight, as not only to destroy the motion communicated, but even to repel them; which is frequently observed to happen when very small shot are discharged by a large quantity of powder; in which case the shot returns back in a direction contrary to that in which they were projected.

AIR USEFUL IN RESPIRATION.

Your own observations and experience have shewn you that the organization of the human frame is a subject worthy of the most serious attention. The nature of the present lecture leads me to explain some parts thereof, and to consider some of those processes that are carrying on within it for the maintenance of it's œconomy. You breathe continually, and you are sensible you could not live without breathing; so that *to live* and *to breathe* have been considered as synonymous terms. *Thou takest away the breath*, says the Psalmist, and they die. This operation, which of all the acts of animal life, is one of the chief and most necessary, is in general called *respiration*. It consists of two actions; one, by which we draw air into the lungs; the other, by which we expel it from them. The

The former of theſe is called *inſpiration*, the latter *expiration*; motions that are more evident or ſenſible than any other that are performed within the body. They begin the moment we are born, and continue as long as we live. They are partly voluntary, and partly involuntary; continuing during ſleep and apoplexy, when the will has no power; but we can on the other hand increaſe, diminiſh, accelerate, or retard theſe motions as often as we pleaſe. The digeſtion of our food—the circulation of the blood, ſecretion, and abſorption, though all eſſential to animal life, are not ſufficient to preſerve it a few minutes, without the conſtant flowing of freſh air into the lungs, and it's reflux into the atmoſphere.

The organs of reſpiration acted upon by the air, are as the firſt wheel in a machine which receives the moving power. Heat preſerves the fluidity of the blood and humours, and acts as an expanding force in the ſtomach, heart, and blood-veſſels; which force is counteracted from without by the atmoſpherical preſſure; for the want of which, the veſſels would be ruptured by the prevailing force within.

Animal life, conſidered only as motion, is maintained like the other motions of nature, by the action of contrary forces; in which there is this wonderful property, that neither appears to have the priority, and whoſe joint effect is a motion, which, *in theory*, is perpetual. The flame of a candle cannot burn without fire, nor be lighted without air; which of theſe is firſt we cannot ſay, for they ſeem co-inſtantaneous, and they work together till the matter fails which they work upon. Thus alſo, when the animal is born into the world, and the candle of life is lighted up, it is difficult to give any precedence to the elemen-

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tary powers by which it is ſupported. The weight of the atmoſphere forces into the lungs (as ſoon as they are expoſed to it's action) that air which is the breath of life; but this could not happen, unleſs the more ſubtil element of fire were to occaſion a rarifaction within; and this reciprocation once begun is continued through life, though it will fail, if the action of the elements upon it ceaſe.*

Air is as eſſential to the combuſtion of bodies as to the ſupport of animal life; ſo much ſo, that even thoſe which are the moſt combuſtible will not flame, but in contact with air; and thoſe which are already inflamed are extinguiſhed on being deprived of it. Thus, if a candle be put under a cloſe receiver, it will be extinguiſhed in a longer or ſhorter time, according to the quantity of air contained in the receiver, and the ſize of the candle. You know, on the other hand, how much fire is quickened and increaſed by a blaſt of air; ſo that air is not only neceſſary to the action of fire, but it would ſeem that the action of fire in general, is the joint action of *air* and *fire* together. It follows alſo, from what has been ſaid, that a candle will burn but for a ſhort time in rarified air, and not at all in vacuo. Air is not only neceſſary for the ſupport of animal life and combuſtion, but it is alſo neceſſary that the air be good, for contaminated air is as pernicious to both as a vacuum. There is, you ſee, a ſtriking relation between the flame of a candle, and the principle of life in an animal body; they are both ſupported by air, and the ſame contaminated air that puts out the candle, extinguiſhes animal life; and that air which is too much rarified to keep a candle burning, is inſufficient for reſpiration.

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* Jones's Sermons, vol. ii. p. 92.

There is no animal found, how seemingly torpid soever it may be, that does not require a needful supply of air, the great parent of health and dispenser of light and warmth. Even fishes, which are furnished with magazines of air, and with the means of appropriating to themselves that which is disseminated in the water, rise from time to time to recruit their stock, and will live but a little time in water from whence the air is extracted. Some animals bear indeed a vacuum better than others. Those which have two ventricles to the heart, as man, quadrupeds, birds, and probably cetaceous fishes, perish therein in a few minutes; while those which have only one ventricle, as reptiles and fish, live in a vacuum for several hours. Besides the deprivation of air in a vacuum, there are other causes which render it destructive of life: among these is the dilatation of the air lodged in the cavities of the body, as well as that contained in the pores of the fluids; for this, being no longer subject to the pressure of the atmosphere, expands and separates the fluids in the capillary vessels, and often bursts them.

Many animals have been tortured in a receiver, merely to observe their manner of dying: thus have men gratified curiosity at the expence of humanity; and that too often without any probability of extending the bounds of science, or promoting the good of mankind. No rational excuse can be given for depriving a poor creature of it's life, (the greatest boon that nature can bestow,) or even to put it in pain, but an object of utility: he, who can from thence procure benefits for the higher orders of animated beings, may be permitted to exert the powers he possesses over the inferior orders of life: but he greatly errs, if he supposes these powers may be used to gratify

gratify wanton curiosity, or the sports of an inordinate fancy.

I shall therefore only relate to you one instance among many: Mr. Boyle took a new-caught viper, and, shutting it up in a small receiver, extracted the therefrom: at first, upon the air's being drawn away, it began to swell; some time after he had done pumping, it began to gape and open it's jaws; it then resumed it's former lankness, and began to move up and down within the receiver, as if to seek for air. After a while it foamed a little, leaving the foam sticking to the inside of the glass: soon after the body and neck grew prodigiously tumid, and a blister appeared upon it's back. In an hour and an half after the receiver was exhausted, the distended viper moved, being yet alive, though it's jaws remained quite distended; it's black tongue reached beyond the mouth, which was also grown blackish in the inside; and in this situation it continued for three hours: but upon the air's being re-admitted, the viper's mouth was presently closed, and soon after opened again; these motions continuing for some time, as if there were still some remains of life. It is thus with animals of every kind; even minute microscopical insects cannot live without air.

The most interesting facts relating to combustion, and even animal life, may be illustrated by a few experiments. Stick a straight piece of wax taper, about four inches long, upon a large cork: then take an empty quart bottle, and hold it by the neck in an inverted position; light the taper, and introduce it quickly into the bottle, taking care not to put it out by touching the sides of the bottle: the cork being large, closes the mouth, and prevents the entrance of any air from without. You have performed this, and you observe that the flame of the taper contracts, grows dim,

 and

and in about one quarter of a minute goes out. Now withdraw the taper, closing the mouth of the bottle with your thumb: light the taper again, and slipping off your thumb, introduce it into the bottle, and you will see that it will be immediately extinguished; the air being so vitiated as to be incapable of assisting the flame. If you wish to preserve the air in the bottle, and try the experiment, when the smoke is subsided, either cork the bottle carefully, or place it in an inverted position, with the mouth under water.

Put eight or ten pieces of money one upon another, in a bason, so as to form a small pile or pillar therein; on these put some cotton or pieces of paper, with a little brimstone; then pour water into the bason, so as to reach about one-fifth or one-sixth part of the height of the pillar of money. After this invert a large plain glass tumbler upon the cotton and it's support. You must incline the tumbler while you are putting it down, in order to let some water in, and some air go out, and make a mark on the outside of the tumbler, exactly coinciding with the level of the water within. This being done, let us take this apparatus into the sunshine; and by means of a burning-glass, throw the collected rays of the sun upon the cotton and sulphur. We have thus inflamed them; the air within being rarified by the heat of the inflamed substance depresses the water. It will sometimes force it's way out: to prevent this you should only use a small quantity of combustible matter, and let the water come up pretty high, within the tumbler, previous to the application of the lens. Having given you this caution, let us observe our apparatus: it is now become as cool as it was at first, and you see the water within the tumbler is risen above the mark; shewing that the combustion of the cotton, &c. occasioned

occaſioned a *diminution* of the air in the glaſs. This diminution of air by combuſtion is a fact of conſiderable importance.

I ſhall relate you another experiment of the ſame kind made by Dr. Hales, which you may repeat at your leiſure. "I took," ſays the Doctor, "a lighted candle about ſix-tenths of an inch in diameter, and put it under an inverted receiver, and with a ſyphon drew the water up to a certain height: then drawing out the ſyphon the water would deſcend for a quarter of a minute, and after that aſcend, though the candle continued burning and heating the air for near three minutes. The water did not aſcend with an equal progreſſion; it would ſometimes move with a ſlow, and ſometimes with an accelerated motion; but the denſer the fumes the faſter it aſcended. As ſoon as the candle was out the doctor marked the height of the water above it's firſt ſituation. The difference ſhewed the diminution of air, which Dr. Hales ſuppoſed was owing to it's elaſticity being deſtroyed by the burning candle. As the air cooled, the water roſe in the receiver, and continued riſing for twenty or thirty hours. He deduced from this experiment that about $\frac{1}{26}$th of the whole quantity of air was deſtroyed by combuſtion.

The reſpiration of animals produces the ſame effect on air as combuſtion, and their conſtant heat is probably an effect of the ſame nature. When an animal is included in a limited quantity of atmoſpherical air, it dies as ſoon as the air is vitiated. This may be ſtated in more general terms: "Whenever combuſtion or any ſimilar proceſs is carried on in a veſſel containing atmoſpherical air, it is found that the proceſs ceaſes after a certain time, and that the remaining air, which is about three-fourths of the whole bulk, is ſo altered as to be incapable of maintaining combuſtion, or

ſupporting animal life." From theſe experiments it is clear that one of the following conſequences muſt take place: 1. The combuſtible body muſt have emitted ſome principle, which, by combining with the air, has rendered it unfit for the purpoſes of combuſtion. Or, 2. It has abſorbed part of the air which was fit for that purpoſe, and has left a reſidue of a different nature. Or, 3. Both events have happened, namely, that the pure part of the air has been abſorbed, and a principle has been emitted, which has changed the orginal properties of the remainder. Theſe circumſtances are only mentioned at preſent, in order to awaken your attention to this curious ſubje, but will be conſidered more fully hereafter.

The following calculation has been made from the data furniſhed by Dr. Hales's experiment: The flame of the candle he uſed occupied about half a cubic inch, and yet conſumed about 78 cubic inches of air in three minutes, which is about 3744 cubic inches in a day, or 791 cubic feet in a year. If fires act according to their cubic dimenſions, which is the neareſt rule we can follow, then a fire of a cubic foot would conſume about 3456 times as much as the candle that is 2733696 cubic feet in a year. Now, ſuppoſing 170000 dwelling-houſes in London (which it was computed to have ſome years back,) and allowing two fires in an houſe, and making no account of candles, lamps, &c. the ſum of cubic feet conſumed in London, amounts to about 230000 millions of cubic feet; and if all other circumſtances in different parts of the world relating to this conſumption of air were conſidered, the quantity uſually allowed to the earth's atmoſphere, would be conſumed in a much ſhorter time than would be imagined. I muſt here, however, be content with a very groſs reckoning, as it would be

be very difficult to obtain materials for making ſuch an unwieldy calculation. In the courſe of theſe lectures it will be ſhewn, that *divine Providence* has provided abundant means for reſtoring the purity of the air, which is continually injured by combuſtion, reſpiration, fermentation, and other proceſſes.

As breathing forms ſo neceſſary and important a function of animal life, I ſhall now endeavour to explain the organs thereof: you will thence perceive with what wiſdom the interior parts of your body are diſpoſed; and no doubt warm emotions of gratitude and adoration will ariſe in your mind from a view of the admirable mechaniſm, and inimitable workmanſhip diſplayed in ten thouſand aſtoniſhing examples, and the exquiſite wiſdom with which every part is adapted to it's peculiar uſe; among theſe we may reckon the mechaniſm of reſpiration: this will be enhanced when you conſider that you breathe twenty times every minute, or 1200 times in an hour, and that every thing is ordered by divine Providence, that nothing happens to ſtop the faculty of breathing when we eat, or drink, or ſleep, though a thouſand hurtful things, without this divine ordering, might enter the windpipe, which would prove inſtant death: for the food which enters the gullet paſſes over the windpipe, which is furniſhed with a lid or valve. When any food advances to the ſtomach, this lid is pulled down and ſhut cloſe; but the moment the morſel is ſwallowed, it inſtinctively opens, and leaves the paſſage free for the neceſſary acceſſion of air.

Galen, an antient and celebrated anatomiſt, obſerves in his treatiſes *De Uſu Part.* lib. iii. "That thoſe treatiſes which diſplay the tranſcendent excellencies of the great CREATOR, compoſe one of the *nobleſt* and moſt *acceptable* hymns.

To acquaint ourſelves with his ſublime perfections, and point out to others his infinite power—his unerring wiſdom—his boundleſs benignity, is," ſays he, " in my opinion, a more *ſubſtantial* act of devotion, than to ſlay hecatombs of victims at his altar, or kindle mountains of ſpices into incenſe." To excite this ſpirit of devotion in you, I proceed to explain ſome of the exquiſite contrivances in the human frame. But not being an adept in the ſcience of anatomy, I muſt hope for ſome candid indulgence in caſe I ſhould offend againſt preciſe anatomical exactneſs.

The lungs are two viſcera contained in the cavity of the thorax or cheſt, *and are there fenced*, according to Job's expreſſion, *with bones and ſinews.* The ribs being turned into a regular arch, are moveable on a kind of center, to aſſiſt the act of reſpiration, and form a ſecure lodgment for the heart and lungs, two of the moſt diſtinguiſhed and important organs of life. The lungs are diſtinguiſhed into right and left, having a broad baſis below, and being terminated above by an obtuſe point. The right, or larger lung, is divided into three lobes; the left or ſmaller into two. The internal fabric of the lungs is compoſed of many ſmall lobes ſeparated from each other by intermediate intervals; which intervals are filled with a looſe cellular ſubſtance, through which veſſels are diſtributed. The ſmaller lobes are ſubdivided into leſſer ones, which are ſtill compoſed of others, but always decreaſing in magnitude; terminating at laſt in very ſmall membranous cells or veſicles, variouſly figured, and full of air, communicating on all ſides with one another. Keil computed the number of theſe veſicles to be 1744,000,000. The pulmonary artery and the pulmonary veins are diſtributed by numerous ramifications throughout the whole

lungs,

lungs, the ſmalleſt veſſels encompaſſing each veſicle like a net.

The external air has acceſs to the lungs by the trachea, or windpipe: the uppermoſt part of this pipe, called the larynx, opens into the throat by an aperture called the *epiglottis*, and communicates with the atmoſphere by the mouth and noſtrils. The trachea is a flexible pipe, compoſed of a ſeries of cartilaginous rings joined by muſcular fibres, and lined with a membrane. This tube deſcending into the lungs, divides and ramifies itſelf in company with the numerous branches of the pulmonary artery, and, together with them and the veins, form the ſpungy ſubſtance called the lungs.

The thorax or cheſt, in which the lungs are placed, is compoſed of bones, cartilages, and muſcles, ſo artfully arranged, that it's cavity may be enlarged or diminiſhed at pleaſure. This is brought about, partly by the elevation of the ribs, partly by the pulling down of the diaphragm, or muſcular partition that divides the cheſt from the lower belly.

This partition naturally bulges convexly upwards, ſo as to encroach conſiderably on the cavity of the thorax; but on inſpiration from a convex, it becomes nearly a plain ſurface, and thus gives a ſpace to the cheſt, which it takes from the lower belly.

The cavity of the cheſt, may, therefore, be enlarged in two different directions: by the elevation of the ribs it becomes wider; by the depreſſion of the diaphragm it becomes deeper.

When the intercoſtal muſcles elevate the cheſt, and when the diaphragm is drawn downwards, the cavity of the thorax is enlarged, and the air within the lungs is expanded in proportion to the acquired ſpace. This air, of courſe, becomes rarer,

and ſpecifically lighter than it was before: it was then in equilibrio with the atmoſphere; and this equilibrium being removed by the expanſion, the external air enters the larynx, and flows through all the branches of the trachea, reſtoring the balance between the ambient air, and that in the lungs.

Whether the cheſt is ſwelled by inſpiration or depreſſed by expiration, the lungs fill the whole cavity, and are always in contact with the pleura, no air being permitted between this membrane and the external ſurface of the lungs; for if there was the lungs could not poſſibly play, as this air would counterbalance the preſſure of the atmoſphere.

So many organs being ſubſervient to reſpiration, and this important function being performed by means of ſuch curious and complicated mechaniſm, no wonder that various attempts have been made to explain the immediate cauſe that excites this function: but the ſubject, after exhauſting much ingenuity, remains ſtill unexplained; and the moſt ſkilful anatomiſt knows no more than the humble peaſant.

All that is known amounts only to this: we have a ſenſation which excites us to expand our cheſt; the action accompanies the inclination, and the air flows into the lungs. When enough is admitted to anſwer the purpoſes of health, we feel an equal deſire of expelling it, which is directly followed by the accompliſhment of that deſire; and thoſe alternate feelings are conſtantly renewed and gratified, with or without reflection, aſleep as well as awake, while life continues.

The quantity of blood which is poured by ten thouſand ſtreams into the lungs, is exceeding great; equal to (or even perhaps greater than) that which is ſent in the ſame time throughout the reſt of the body;

body; proving that there is ſome conſiderable uſe peculiar to this viſcus. Phyſiologiſts are not agreed with regard to all the uſes of the lungs, or the benefits reſulting to the body from breathing; ſome of theſe are evident and undiſputed. The correſpondence of the actions of the lungs with thought and ſpeech cannot be doubted; for it is by their means the voice is modulated, and that we have the power of ſpeech. When we think tacitly we breathe tacitly; when we think deeply we breathe deeply; drawing in and relaxing, compreſſing, and elevating the lungs according to the thought. By the air entering the noſtrils, and conveying effluvia, breathing becomes inſtrumental to the ſenſe of ſmelling. Every thing in the body is ſo connected, that when the lungs reſpire all and every thing in the body is actuated by the reſpiration of the lungs, and the pulſation of the heart; for the heart is joined to the lungs by it's auricles, and alſo all the viſcera of the whole body are joined by ligaments to the cavity of the breaſt; and that in ſuch manner, that all and every part is affected by the reſpiratory motion. When the lungs are inflated, and the thorax expanded by the ribs, the pleura is alſo dilated, and the diaphragm preſſed downward; and with theſe all the inferior parts of the body, which are connected to them by ligaments, receive ſome action from the action of the lungs; the alternations of reſpiration entering or affecting the inmoſt receſſes of the viſcera. There is a perfect conjunction of the motion of the heart and lungs with all and every part of the body: to render this conjunction more complete, the heart itſelf is alſo in the pulmonary motion, lying in the boſom of the lungs, adhering to them by it's auricles, and reſting upon the diaphragm, from which alſo it's arteries participate of the pulmonary motion. The ſtate of the

the lungs depends alſo upon the blood from the heart; for when the influx of blood ceaſes, reſpiration ceaſes.

There is a moſt intimate connection between the act of reſpiring and the circulation of the blood. When reſpiration is for a ſhort time interrupted by the fumes of burning ſulphur, by mephitic air, or by remaining ſome minutes under the water, the action of the heart ceaſes: but, in many caſes of this kind, the motion of the heart may, and frequently has been renewed, by blowing air into the lungs, &c. In perſons ſeemingly dead, from a ſuſpenſion of reſpiration, if the lungs can be excited to act, the motion of the heart inſtantly commences, the circulation of the blood is reſtored, and life recovered.

The blood of the heart is purified in the lungs from things indigeſted, and attracts from the air a neceſſary nouriſhment. This is evident, not only from the influx of the blood, which is venous, and conſequently replete and recruited with chyle collected from food and drink, and therefore unqualified in this ſtate to perform the vital tour. It is evident alſo, from the expirations which are humid, and often manifeſt their operation from their *odour;* the effluvia thus exhaled being ſo corrupted, that they would prove fatal if retained in the lungs, or if breathed by other animals; and further, from the diminiſhed quantity of blood returned into the left ventricle of the heart. That the blood attracts from the air a ſuitable nouriſhment, is evident from the vaſt quantity of exhalations and effluvia with which it is impregnated, and which flow into the lungs with it: in the ſpongy cells of this amazing laboratory it imbibes the influence of the external air. Hence it is that in the air-cells, or inmoſt part of the lungs, there are in great abundance ſmall veins with mouths,

mouths, which abſorb ſuch things; and alſo that the blood returned into the left ventricle of the heart is changed into arterial blood, and becomes florid; proving that the blood is here purified from things heterogeneous, and nouriſhed with things homogeneous.*

Reſpiration gives riſe to many other functions of the animal œconomy. All animals furniſhed with lungs expreſs their wants, their affections, and averſions; their pleaſures and pains, either by words or by ſounds peculiar to each ſpecies: theſe different ſounds are produced by ſtraitening or widening the windpipe, or the paſſage through which the air paſſes in reſpiration. The inferior animals are by this enabled to expreſs themſelves in ſuch manner as to be intelligible to every individual of the ſpecies.

To man alone divine Providence has given the gift of ſpeech, the means of expreſſing his various feelings and ideas, by regular, extenſive, and eſtabliſhed combination of articulate ſounds. Speech is performed by a very various and complicated machinery. In ſpeaking, the tongue, the lips, the jaws, the whole palate, the noſe, the throat, together with the muſcles, bones, &c. of which thoſe organs are compoſed, are all employed to modulate the ſound, and form the voice, and produce ſpeech, which procures to us ſuch innumerable benefits. This combination of organs we are taught to uſe when ſo young, that we are hardly conſcious of the laborious taſk, and far leſs of

* Diemerbrocc† mentions finding duſt in the veſiculæ of the lungs of two aſthmatic perſons that he opened: one a ſtone-cutter's man, the veſiculæ of whoſe lungs were ſo ſtuffed with duſt, that, in cutting, his knife went as if through a heap of ſand. The other was a feather-driver, who had theſe bladders filled with the fine duſt, or down of feathers.

† Derham's Phyſico-Theology, Logographic edit. p. 211.

of the manner by which we pronounce different words and letters.

It is from GOD alone that man has the faculty of ſpeech, the power of *articulating* his *voice*, and of giving it a variety of diſtinct ſounds at his own will and choice. It is HE alone who provided man with the inſtruments by which he ſo articulates; who formed the human *mouth* and *tongue* to be much more pliant, moveable, and flexible than the ſame parts of other animals. It is HE who furniſhed thoſe immediate organs of ſpeech in man, with peculiar muſcles, by which he can give to his mouth any degree of aperture and curvature; and to his tongue, any kind of flexure he pleaſes, by an application of this agile member to any part within it's ſphere and motion.

Abſurd, indeed, is the idea of thoſe who embrace the idea of *Diodorus Siculus*, "That the firſt men lived for ſome time in woods and caves, after the manner of beaſts, uttering only confuſed ſounds." It is hardly poſſible for any man to form a judgment more contrary to the nature of things: for does not the nature of almoſt all animals, beaſts, and birds ſhew us, that they have a natural untaught language, not conſiſting of *confuſed ſounds*, but altogether diſtinct, by an articulate difference, and highly intelligible to every one of the ſame ſpecies? If, therefore, the nature of things will allow us to ſuppoſe that man was created as perfect in his kind, as the animals were in their's, then the nature of things will oblige us to affirm, that the firſt men had from nature an untaught language, as ſuitable to their nature, as uſeful, as diſtinct, and intelligible to themſelves, as that of beaſts or birds is to them, in their ſeveral kinds. The language of every creature is natural, not taught; it is as much the effect of *it's whole nature*, the joint operation of it's ſoul, ſpirit,

ſpirit, and body, as it's life is; and is articulate, or not articulate, good or evil, harmonious or horrible, juſt as the life of the creature poſſeſſes more or leſs of a celeſtial or earthly harmony. The whole philoſophy of the language of all creatures, whether in heaven, on earth, or in hell, is to be found in theſe words of our GOD and SAVIOUR, *That out of the abundance of the heart the mouth ſpeaketh.*

If mankind had not a *natural* language, they could never have invented an artificial, by their reaſon and ingenuity; for all artificial language ſuppoſes ſome compact or agreement to affix a certain meaning to certain ſigns: therefore, there muſt be compacts or agreements before the uſe of artificial ſigns; but there can be no compact or agreement without ſigns, nor without language; and therefore there muſt be a natural language before any artificial language can be invented.*

Reſpiration is concerned when we laugh; for to do this we make a full inſpiration, which is ſucceeded by frequently interrupted and ſonorous expirations. When the titillation and conſequent expulſive expirations are great, whether they ariſe from the mind or body, they interrupt the breathing to ſuch a degree as to endanger ſuffocation. Moderate laughing promotes health, by agitating the whole body: it quickens the circulation of the blood, gives cheerfulneſs to the countenance, and baniſhes anxiety from the mind.

We employ nearly the ſame organs in weeping as in laughing: it commences with a deep inſpiration, which is ſucceeded by ſhort, broken, ſonorous, and diſagreeable expirations. The reſpiratory organs are neceſſary in the acts of coughing, ſneezing, yawning, ſinging, ſighing, and many other acts of the animal œconomy.

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* Reid's Inquiry into the Human Mind, p. 98.

By reſpiration odours are conveyed to the noſe. You will find from obſervation that all animal and vegetable bodies, and probably all or moſt other bodies expoſed to the air, are continually ſending forth very ſubtle effluvia in their various ſtates of life, and growth, fermentation, and putrefaction. The ſmell of plants, and of other bodies, is cauſed by theſe volatile parts, and are ſmelled wherever they are ſcattered in the air. The acuteneſs of this ſenſe in ſome animals ſhews that theſe effluvia ſpread far, and muſt be inconceivably ſubtil. Theſe effluvia are drawn into the noſtrils along with the air, which is continually paſſing through them in inſpiration and expiration.

We are informed by anatomiſts that the membrane pituaturia, and the olfactory nerves, which are diſtributed to the villous parts of this membrane, are the organs deſtined by divine Providence for this ſenſe: ſo that when a body emits no effluvia, or when they do not enter into the noſe; or when the pituary membrane, or olfactory nerves are rendered unfit to perform their office, it cannot be ſmelled.

You will obſerve that, notwithſtanding theſe mechanical inſtruments, it is evident that neither the organ of ſmell, nor the medium, nor any motions we can conceive, excited in the abovementioned parts, or in the nerve or animal ſpirits, do in the leaſt reſemble the ſenſation of ſmelling. It is impoſſible to conceive or believe ſmelling to exiſt of itſelf without a *mind*, or ſomething that has the power of ſmelling, and of which it is called a ſenſation, an operation, or feeling. The faculty of ſmelling is ſomething very different from the ſenſe of ſmelling; for the faculty may remain when you have no ſenſation, and the mind is no leſs different from the faculty, for it continues

continues the ſame individual being when that faculty is loſt.

I ſhall now ſhew you the divine wiſdom manifeſted by adapting the organs of different creatures to their particular ſtates of receiving, reſpiring, &c. the air, and I ſhall proceed to lay before you one or two remarkable inſtances. Thus, though birds reſpire by means of lungs, yet are they ſo conſtructed that the air is tranſmitted to almoſt every part of their bodies. The lungs of birds are ſo firmly attached to the diaphragm, the ribs, the ſide, and the vertebræ, that they can admit of very little dilation or contraction. Inſtead of being impervious, the ſubſtance of the lungs, as well as of the diaphragm, to which they adhere, is perforated with many holes or paſſages for the tranſmiſſion of air to the other parts of the body: to each of theſe perforations a diſtinct membranous bag is joined; theſe bags are extremely thin and tranſparent; they extend through the whole of the abdomen, are attached to the back and ſides of that cavity, and each of them receives air from their reſpective openings into the lungs. The cells in which birds receive air from the lungs are found not only in the ſoft parts, but in the bones.

Mr. John Hunter has made a variety of experiments to diſcover the uſe of this general diffuſion of air through the bodies of birds; and from theſe we find, that it prevents their reſpiration from being ſtopped or interrupted by the rapidity of their motion through a reſiſting medium. The reſiſtance of the air increaſes in proportion to the celerity of the motion: were it poſſible for a man to move with a ſwiftneſs equal to that of a ſwallow, the reſiſtance of the air, as he is not provided with reſervoirs ſimilar to thoſe of birds, would ſoon ſuffocate him.

Cetaceous fiſhes reſpire like man, by means of lungs, and are, of courſe, obliged at certain intervals to come to the ſurface, in order to throw out the former air, and to take in a freſh ſupply. Other ſpecies of fiſh are furniſhed with gills inſtead of lungs, through which they reſpire both water and air; for air is univerſally diffuſed or mixed with every portion of water; beſides this, however, it is neceſſary that the water in which they ſwim, ſhould have a free communication with the air; for they cannot live long, if deprived of this vivifying element.

Inſects are not furniſhed with lungs ſimilar to thoſe of men, quadrupeds, &c. but as the tranſmiſſion of air into their bodies, is neceſſary for continuing the principle of life, they are furniſhed with peculiar inſtruments and apparatus for this indiſpenſible purpoſe. For a deſcription of theſe I muſt refer you to my Eſſays on the Microſcope; reciting only one inſtance, that of the larva of the *muſca pendula*, *Lin.* as deſcribed by a very ingenious naturaliſt.

Being out on an excurſion with ſome friends, they were ſtruck with the appearance of a little puddle of reddiſh water, the ſurface of which was in continual motion. On taking up ſome of this water they found a number of dirty ſhapeleſs animals, which had much the appearance of common maggots, but much uglier; they were brown, thick, ſhort, and furniſhed with tails. "I ordered them," ſays our naturaliſt, "to be laid down on the graſs, and diſpatched a ſervant for ſome clear water, and then began to explain their nature, origin, and properties.

"I had often informed my companions that none of the winged inſects were hatched from the egg, but that they were all firſt produced in the form of worms, maggots, or caterpillars; or, in other

other words, covered with ſkins, under which they *live*, *move*, and *eat*, with the appearance of animals very different from their parents: they were not therefore ſurprized, when I informed them, that the creatures before us were not in their ultimate ſtate, but were the produce of the bee-fly (*muſca pendula.*) This fly is inſtructed by *the univerſal Guide and Guardian of Nature*, to lay it's eggs about the edges of the water. It's young, while in the worm ſtate, are to live and feed in the water; but the female cannot depoſit her eggs in that element, without periſhing in the attempt: ſhe lays them on dry land, near the place proper for the reſidence of her young, who are inſtructed by the ſame guide to make their way to the water; and, finally, when they have acquired their full growth, and the animal is ready to burſt forth into a new life, and enjoy the regions of the air, it again quits the water, that this great event may be performed at land.

"The ſervant being returned with ſome water, he obſerved, that though reſpiration is neceſſary to all animal life, yet it is variouſly performed in the ſeveral ſpecies; and that, while man and the generality of other animals reſpired by the mouth, this creature reſpired by the tail.

"The inſects we were examining were about half an inch long, and their tails near an inch. The water in the glaſs was proportioned at firſt to this meaſure in depth: on throwing ſome of the inſects into it, their bodies naturally ſunk with the head downwards; and, while they ſeemed ſearching after food about the bottom, the extremities of their tails were ſeen juſt above the water, and in continual motion.

"My companions, who have long ſince learnt to make every obſervation of this kind a ſource of adoration to the ſupreme Creator, Diſpoſer, and

Preſerver of all things, were admiring the care of his providence, in contriving thus amazingly that a poor creature ſhould not be ſuffocated while it fed. I ordered a pint more water to be thrown into the glaſs, and they all cried out againſt my deſtroying theſe unfortunate animals; but their admiration was raiſed much higher than before, when I told them they would receive no harm, for they had a power of lengthening their tail about an inch; but that they were not left without means of life in a much greater depth of water. On adding a quart more water, it was ſoon found that the apparent tail of the inſect was a mere tube, containing within it another much ſmaller, yet ſufficiently large for to convey all the air that was neceſſary to this animal; a fine ſlender pipe being darted up out of this, and extended to the new ſurface: on raiſing the water two inches higher, the pipe was lengthened as far as was neceſſary, and ſo on till the limits of the glaſs ſuffered us to carry the experiment no further."

LECTURE V.

OF SOUND.

FROM explaining the efficacy and action of air in reſpiration, &c. I proceed to bring you acquainted with it's agency in producing *ſound*. The ſenſe of *hearing*, by which we receive ſounds, adds infinitely to our happineſs: it opens to us a wide field of pleaſure; though it is leſs extenſive in it's range than that of ſight, yet it frequently ſurmounts obſtacles that are impervious to the eye, and communicates information of the utmoſt importance, which would otherwiſe eſcape from, and be loſt to the mind.

Sound,

Sound, by it's divergence, extends in every direction, visiting a thousand with the same ease as one individual; freely communicating it's tidings wherever attention excites an auditory. Every one feels that musical sounds are pleasing to the sensitive soul; I mean not here the *harmony* of sounds, for the rational mind only can be sensible of these: I mean such simple sounds as are tuneful; especially the *clear*, the *smooth*, and the *lively*.

You know that many species of the smaller winged tribes take so much pleasure in sounds of this kind striking grateful on their ear, and exhilarating their spirits, that to give themselves this pleasure, seems to employ the greater part of their wakeful hours, and to constitute the principal enjoyment of their lives. They are endued by *Divine Providence* with the power of forming and uttering those delightful sounds; and HE has been so liberal in this blessing, that the air in every wood and grove is filled with their various and artless melody: nor can imagination, perhaps, ever conceive any thing more delightful, than to have all the songsters of the grove collected under the beam of the breaking-out sun, and pouring forth the sensations of their hearts in a profusion of wild and complicated melody.

The metaphysician considers the idea of sound in the mind: the anatomist describes the impression it makes upon the ear, and the manner in which it is conveyed from thence to the brain: the natural philosopher investigates it in the substance where it is produced, and in the medium by which it is conveyed to the ear. The savage cannot comprehend how we can convey our thoughts to one another by writing; the communication thereof by sounds would appear as wonderful to us, but that we fall into it before we know what wonder is; *that is, before we have*

gained any experience to which new appearances may ſeem repugnant.

Sound ariſes from a vibratory or tremulous motion, produced by a ſtroke on a ſonorous body; which motion it communicates to the ſurrounding medium, which carries the impreſſion forward to the ear, and there produces it's ſenſation. In other words, ſound is the ſenſation ariſing from the impreſſion made by a ſonorous body upon air, or water, &c. and carried along by either fluid to the ear.

Three things are therefore neceſſary to the production of ſound: 1. A ſonorous body to give the impreſſion; 2. A medium to convey it as a vehicle; 3. The ear to receive the impreſſion.

Strictly ſpeaking, ſonorous bodies are thoſe whoſe ſounds are diſtinct, comparable with each other, and of ſome duration; ſuch as thoſe of a bell, a cord of a violin, and not ſuch as give only a confuſed noiſe; as that made by a ſtone falling on the pavement: to be ſonorous, a body muſt be elaſtic; one whoſe parts are capable of a vibratory motion when they are forcibly ſtruck by any kind of plectrum.

* Gold, ſilver, copper, and iron, which are elaſtic metals, are alſo ſonorous; but lead, which is unelaſtic, gives no ſound. Tin, which in itſelf has very little more ſound than lead, highly improves the tone of copper, when mixed with it. Bell-metal is formed of ten parts copper, and one of tin. Each of theſe is ductile when ſeparate, though tin is only ſo in a ſmall degree, yet form a third ſubſtance almoſt as brittle as glaſs. So wonderful is the power of tin in this reſpect, that even the vapour of it, when in fuſion, will give brittleneſs to gold and ſilver, the moſt ductile of all metals.

The claſſes of ſonorous bodies are chiefly theſe three:

* Jones's Phyſiological Diſquiſitions, p. 293.

three: 1. *Bells* of various figures and magnitudes; of these, those that are formed of glass have the most pure and elegant tone; and as glass is very elastic the sound thereof is powerful: 2. *Pipes* of wood or metal: these, by means of a vibrating plate of metal, to perform the office of a larynx, may be so constructed as nearly to imitate the human voice: 3. Strings, formed either of metallic or animal substances. The sounds they give are more grave or more acute, according to the thickness, length, and tension of the strings: when fir-wood, which, from it's fibrous construction, is very elastic, is combined with strings; or, when strings are agitated by horse-hair, the effect and powers of one sonorous body are assisted by another.

Air is universally allowed to be the ordinary medium of sound; the medium by which sounds are propagated from sonorous bodies, and communicated to the ear: this we shall easily prove by an experiment on the air-pump. I include this bell within the receiver, which, while full of common air, sounds nearly as well as before. I shall now work the pump, and you will perceive that the sound diminishes in proportion to the degree of the exhaustion; so much so, that when the air is nearly extracted, the sound is almost lost. An objection has been made to the conclusion we have drawn from this experiment; namely, that when the air is exhausted from within, the pressure from the incumbent air on the exterior surface will prevent the transmission of the sound, in the same manner as a body is prevented from sounding, by sustaining a pressure on any *part* of it. But this objection has been well obviated; for if the air in the receiver be condensed, instead of being exhausted, the sound so far from being extinguished will be increased, though there is as great an inequality of pressure on the two surfaces in

this caſe as in the former. Hawkſbee has ſhewn, by a ſeries of well-conducted experiments, that air is propagated further by denſe than by rarified air; and that air as denſe again as common air will convey ſound twice as far; and thence concludes that ſound is increaſed, not only in a direct ratio of the denſity of the air, but as the ſquare of the denſity. M. Briſſon has ſhewn, that if a ſonorous body be placed in an elaſtic fluid, whoſe denſity is greater than that of common air, that the ſound would be much ſtronger in the fluid than in the air: his experiment was made with the *gas acide carbonique*.

But though air is the general vehicle of ſound, yet ſound will go where no air can convey it: thus, the ſcratching a pin at one end of a long piece of timber, may be heard by an ear applied near the other end, though it could not be heard at the ſame diſtance through the air; and two ſtones being ſtruck together under water, may be heard at a much greater diſtance by an ear placed under water in the ſame river, than it can be heard through the air; Dr. Franklin thinks he has heard it a mile. Theſe effects muſt be owing to the intervention of ſome cauſe more moveable and powerful than air itſelf.

When any elaſtic body is ſtruck, that body, or ſome part of it, is made to vibrate. This is evident to ſenſe in the ſtring of a violin or harpſichord; for you may perceive by the eye, or feel by the hand, the trembling of the ſtrings, when by ſtriking them they are thereby made to ſound.

If a bell is ſtruck by the clapper on the inſide the bell is made to vibrate: the baſe of the bell is a circle; but, by ſtriking any part of this circle on the inſide that part flies out; ſo that the diameter which paſſes through this part of the circular baſe, will be longer than the other diameter.

meter. The baſe, by the ſtroke, is changed into an oval, whoſe longer axis paſſes through the part againſt which the clapper ſtruck: the elaſticity of the bell reſtores the figure of the baſe, and makes the part which was forced out of it's place return back to it's former ſituation; from whence the ſame principle throws it out again; ſo that the circular figure of the baſe will again be changed into an oval; only now the ſhorter axis will paſs through the part that was firſt ſtruck.

The ſame ſtroke which makes the bell vibrate occaſions the ſound; as the vibrations decay the ſound grows weaker. Your ſenſes will convince you that the parts of the bell are in a vibratory motion: if you lay your hand gently thereon, you will feel this tremulous motion; or if you throw ſmall pieces of paper on the bell, the jarring thereof will put them in motion. Theſe vibrations cauſe ſimilar undulations in the air; and as the motions of one fluid may often be illuſtrated by the motions of another, the inviſible motions of the air have been not unaptly compared to the viſible waves of water, when ſuddenly produced by throwing a ſtone therein. Theſe waves ſpread themſelves in all directions in concentric circles, whoſe common center is the ſpot where the ſtone fell; and when they ſtrike againſt a bank, or any other obſtacle, they return in the contrary direction to the place from whence they proceeded. Sound expands in like manner in every direction, and the extent of it's progreſs is in proportion to the impulſe on the vibrating cord or bell. Such is the yielding nature of fluids, that when other waves are generated near the firſt waves, and others again near to theſe, they will all perform their courſes amongſt each other without interruption; thoſe that are coming back will paſs by thoſe that are going forward, or even through them: thus,

 if

if you throw a ſtone into a pond, and immediately after another, and then a third, you will perceive that their reſpective circles will proceed without interruption, and ſtrike the ſhore in regular ſucceſſion. The atmoſphere in the ſame manner poſſeſſes the faculty of conveying ſounds in the moſt rapid ſucceſſion or combination, as diſtinctly as they were produced. It poſſeſſes the power, not only of receiving and propagating ſimple and compound vibrations in direct lines from the voice or inſtrument, but of retaining and repeating ſounds with equal fidelity, after repeated reflexion and reverberation, as you may be eaſily convinced by the ſound of a French-horn among hills.

A familiar and eaſy experiment ſhews the vibratory motion that produces ſound. Take a common poker, and tying on a garter at top, ſo that both ends of the garter may be left at liberty: roll theſe round the firſt finger of each hand, and ſtop the ears cloſe with theſe fingers; ſtrike the poker againſt any hard ſubſtance, and you will hear an amazing deep tone, ſcarcely equalled by the largeſt and deepeſt bell.

Here is a drinking-glaſs nearly filled with water which gives a ſweet ringing ſound: on my rubbing the top of my finger with a gentle equable motion along the rim, the ſurface of the water is fretted and curdled into the fineſt waves by the undulations of the air; yet ſuch is the nature of theſe undulations, that the flame of a candle is not viſibly agitated when placed near a ſonorous body of the largeſt magnitude. It does not appear that theſe undulations produce any progreſſive flux of the particles of air, but that they proceed from a vibratory motion of theſe particles in their proper places; ſo that the motion producing ſound is not ſimilar to that of wind; yet

the motion of the wind can act as a cause of sound, which you have no doubt observed with the Eolian harp.

Scarce any thing was done on this subject of any importance, till the sagacity of our incomparable Newton first explained the laws, according to which the ærial pulses are propagated. It was he who first discovered that the pulses of the air are propagated in all directions round the sounding body; and that during their progress and regress they are twice accelerated, and twice retarded, according to the law of a pendulum vibrating in a cycloid; and these discoveries are the foundation of almost all our reasoning on sound.

Before we proceed it will be necessary to make you a little acquainted with some properties of the pendulum, of which I shall probably treat more at large in one of the subsequent lectures.

When two pendulums vibrate, which are exactly of the same length, their vibrations are performed in equal times: if they set out together to describe equal arcs they will consent together in their motions till they are at rest; and if the arcs be small, all the vibrations of each, when compared with one another, will be *isochronous*. But if one of these pendulums is twice as long as the other, the vibrations of the longer will be twice as slow as those of the shorter; in other words, the times of their vibrations will be as the square root of their lengths.

A pendulum is fixed to one point, a musical string is extended between two points, and in it's vibrations may be compared to a double pen vibrating in a very small arc, whence strings of different lengths may consent in their motions after the manner of pendulums: but then it must be noted, that as a musical string is two pendulums, not one only, it is not necessary to quadruple the length,

length, in order to make the time of a vibration twice as great; it will be ſufficient only to double it; and whatever height the pendulum falls from on one ſide, ſo much it will riſe on the other; ſo will the elaſtic muſical ſtring continue to vibrate from one ſide to the other for ſome time, and each of it's little vibrations, like thoſe of a pendulum, will be performed in times exactly equal to each other.

Thus do we gain, from the analogy between a pendulum and a muſical ſtring, a more adequate conception of a ſubject that could never be underſtood till this analogy was diſcovered: it explains why every muſical ſound preſerves the ſame pitch from beginning to the end, as long as it can be diſtinguiſhed by the ear; and why the pitch is ſtill unvaried, whether the ſound be loud or ſoft; and all this, becauſe the vibrations of the ſame pendulum, whether they are longer or ſhorter, when compared among themſelves, are found to be all deſcribed in equal times till the pendulum be at reſt; the difference of the ſpace which is moved over, compenſating for the ſlowneſs of the motion in it's decay.

To illuſtrate ſtill further this ſubject, ſtretch a piece of catgut upon theſe two pins: I now lay hold of it in the middle, and pull it upwards; I let it go, and you obſerve that it firſt ſtraightens itſelf, or returns to it's original poſition, then bends itſelf as far the contrary way; the ſtring acquiring ſufficient force when it was bent one way to bend itſelf as far the other, and to continue moving backward and forward, till the reſiſtance of the air and the friction deſtroys the velocity which the ſtring acquires by the force of elaſticity. It is obvious, that when the ſtring is thus let fly from the finger, whatever be it's own motion, ſuch alſo will be the motion of the particles

ticles of air that fly before it; the air will be driven forward, and by that means condenſed. When this condenſed air expands itſelf, it will expand itſelf not only towards the ſtring; but as the elaſticity thereof acts in all directions, it will alſo expand itſelf forwards, and condenſe the air that lies beyond it: this laſt condenſed air, by it's expanſion, will produce the ſame effect on the air that lies ſtill further forwards; and thus the motion produced in the air, by the vibration of the elaſtic body being conſtantly carried forward, will be conveyed to the ear. The contiguous parts of the air going forwards and backwards by turns, will be ſubject to the like vibrating motion with the parts of the ſonorous body; and as the firſt parts were condenſed in their progreſs, and relaxed in their regreſs, ſo will the other parts as often as they go forwards be condenſed, and as often as they go backwards be relaxed: and therefore they will not all go backwards and forwards together; for then their reſpective diſtances would be always the ſame, and conſequently they could not be alternately rarified and condenſed; whereas they meet each other when they are condenſed, and go from each other when they are rarified; one part of them muſt therefore neceſſarily go forwards, whilſt the other goes backwards by alternate changes from firſt to laſt.

As theſe condenſations of air are what ſtrike *(pulſant)* upon the ear, or upon any obſtacle that is in their way, they are called *pulſes;* ſound in the air through which it is conveyed conſiſts of ſuch pulſes. It will be neceſſary to relate to you ſomewhat of the nature of theſe pulſes and their properties: for the demonſtration, as purely mathematical, I muſt refer you to thoſe writers who have written particularly on this ſubject.

But

But here I muſt obſerve that theſe pulſes are ſometimes produced without ſuch vibrations of the ſounding body. In theſe caſes we have to diſcover by what cauſe theſe condenſations or pulſes may be produced, without any vibrations in what is conſidered as the ſounding body. We have two inſtances of this ſort; one in wind inſtruments, ſuch as a flute, or an organ-pipe; the other in the diſcharge of a gun: in an organ, or in a flute, the air which is driven through the pipe ſtrikes againſt the edge of the lips in it's paſſage, and, by being accumulated there, is condenſed; and from this condenſation the pulſes are propagated. When a gun is diſcharged, the powder upon taking fire expands the air about it all at once, and conſequently condenſes the air which encompaſſes the ſpace where this expanſion happens; for whatever air is driven out of that ſpace where the expanſion is made will be forcibly driven into the ſpace all round it. This condenſation is the firſt pulſe, and as this expands again by it's elaſticity, pulſes of the ſame ſort will be produced and propagated forwards.

The parts of all ſounding bodies vibrate according to the laws of a cycloidal pendulum; as the vibrations therefore of the ſonorous body follow each other at equal intervals of time, the pulſes which are excited by thoſe ſeveral vibrations will alſo ſucceed each other at the ſame equal intervals of time.

Sounding bodies propagate their motions on all ſides directly forwards, by ſucceſſive condenſations and rarifactions, and ſucceſſive going forwards and returning backwards of the particles; ſo that ſound is driven in all directions backwards and forwards, upwards, downwards, and on every ſide; the pulſes go on ſucceeding each other, but one without-ſide the other, like circles in diſturbed

turbed water; or, rather in concentric ſhells, ſhell above ſhell, as we ſee in the coats of an onion.

The pulſes are thoſe parts of the air which vibrate backwards and forwards; and which, by going forward, ſtrike againſt obſtacles. The latitude of a pulſe is the rectilineal ſpace through which the motion of the air is propagated during one vibration of the ſounding body.

All pulſes move equally faſt: this has been proved by experiment; and it is found that they deſcribe 1070 Paris feet, or 1142 London feet, in a ſecond, whether the ſound be loud or low, grave or acute.

Sounds may differ from one another both with reſpect of their tone, and in reſpect of their intenſity or ſtrength: in reſpect of their tone they are diſtinguiſhed into grave and acute: in reſpect of their intenſity they are diſtinguiſhed into loud or ſtrong, low or weak. The tone of a ſound depends upon the *time* that an impreſſion continues, and is not altered by the diſtance of the ear from the ſounding body. But the intenſity or ſtrength of any ſound depends upon the force with which the particles of air, as they are condenſed, ſtrike the ear; and this force is different at different diſtances; ſo that a ſound which is very loud, when we are near the body that produces it, will be weaker if we are farther from it; and the diſtance may be ſo great that we cannot hear it at all. Mathematicians ſhew *that the intenſity of ſound at different diſtances from the ſounding body, is inverſely as the ſquare of the diſtances.*

Sound moves with the ſame velocity at all diſtances from the ſounding body. The ſound of a cannon, or a bell, moves at the rate of 1142 feet in a ſecond at all diſtances from the gun or bell. If it moves at this rate for the firſt mile, it will move

move at the ſame for the ſecond mile: ſo that a perſon who is within one mile of a cannon when it is diſcharged, will hear the report juſt as ſoon again as another who is at the diſtance of two miles. The velocity of ſound does not decreaſe as it is propagated forwards, but continues the ſame from the firſt to the laſt: but, though the velocity of ſound is not altered, while each pulſe is produced in an equal time; ſo that though the velocity with which the particles vibrate decreaſes as the ſound ſpreads, and conſequently decays till it ceaſes entirely; yet the velocity with which the ſound itſelf is propagated, continues the ſame to the laſt; or the velocity with which it is moving at the time that it ſtops, is the ſame velocity with which it began to move.

Sounds of different tones move with the ſame velocity. This is very evident; for a peal of bells are heard in the ſame order in which they are rung, whether we are near or at a diſtance.

Sounds of different intenſities are propagated with the ſame velocity. A low ſound cannot be heard indeed, ſo far as the loud one may: yet ſounds, either low or loud, will be conveyed in an equal time to any equal diſtance at which either of them can be heard. The report of a cannon does not move faſter, or paſs over a given ſpace, ſooner than the ſound of an elaſtic ſtring.

The principal cauſe of the *decay of ſound* is the want of perfect elaſticity in the air: whence it ariſes that every ſubſequent particle has not the entire motion of the preceding particle communicated to it, as in the caſe of equal and perfectly elaſtic bodies; conſequently the farther the motion is propagated, the more will the velocity with which the particles move be diminiſhed; the condenſation of air will be diminiſhed alſo, and the

the farther the pulse is propagated the more is the density; and consequently the impulse on the drum of the ear diminished.*

And that the defect of perfect elasticity in the air is a principal cause of the decay of sound, appears from this; that sounds are perceived more distinctly when north, north-east, and easterly winds prevail, at which time the air is dry, and consequently more elastic; for vapours diffused through the atmosphere, unless dilated by intense heat, diminish the spring of the air.

Sound requires a sensible time for it's propagation, or passage from one place to another: on discharging a gun the report is not heard till some time after the flash has been seen; for light moves much swifter than sound, coming from the sun in eight minutes, or 72420 leagues in a second; so that the velocity of light may be considered as instantaneous: and as sound takes up a considerable time in it's passage, the interval between the flash and report of the gun shews us the space that is passed over in a given time.

From a set of curious experiments made at different times by different people, we obtain the following results: 1. That the mean velocity of sound is about one mile in nine half-seconds and a quarter, or 1142 feet in one second of time: 2. That all sounds, whether they be weak or strong, great guns, or small, &c. have the same velocity: 3. That it moves through equal spaces in equal time, being the same at the end as at the beginning: 4. That it is the same by night or by day, hot or cold weather, winter or summer: 5. That

* Other causes of the decay of sound have been assigned, but they have been proved to be inadequate to the purpose by Mr. Young, of Dublin, in his Inquiry into the Phenomena of Sound.

5. That it is alſo the ſame whether the cannon be directed to or from the place: 6. That there is a ſmall difference in the velocity of ſounds, with or againſt the wind: 7. It is alſo ſomewhat augmented or diminiſhed by a difference in the ſtrength or weakneſs of the wind.

OF THE SPEAKING TRUMPET.

The augmentation of ſound by this inſtrument, depends on it's reflexion from the tremulous ſides of the tube, which reflexions, by conſpiring to propagate the pulſes in the ſame direction, increaſe it's intenſity. Farther, when we ſpeak in the open air, the effect on the tympanum of a diſtant auditor is produced merely by a ſingle pulſe: but when we uſe a tube all the pulſes propagated from the mouth, except thoſe in the direction of the axis, ſtrike againſt the ſides of the tube, and every point of impulſe becoming a new center, from whence the pulſes are propagated in all directions, a pulſe will arrive at the ear from each of thoſe points. Thus, by the uſe of a tube, a greater number of pulſes are propagated to the ear; and conſequently the ſound increaſed. The confinement of the voice may alſo have ſome effect, though not ſuch as is generally aſcribed to it;* for the condenſed pulſes produced by the naked voice, expand freely every way; but in tubes the lateral expanſion being diminiſhed, the direct expanſion will be increaſed, and conſequently the velocity of the particles and the intenſity of the ſound. The ſubſtance of the tube has alſo it's effect; for the more ſuſceptible it is of tremulous motions, the ſtronger is the effect.

If

* For the errors in accounting for the effects of the tube, ſee Mr. Young's Inquiry into the Phenomena of Sound.

If the tube be laid on any non-elaſtic ſubſtance it deadens the ſound, becauſe it prevents the vibratory motion of the parts. The ſound is increaſed, if the ſpeaking trumpet be ſuſpended in the air, becauſe the agitations are then carried on without interruption. Theſe tubes ſhould increaſe in diameter from the mouth-piece, becauſe the parts vibrating in directions perpendicular to the ſurface will conſpire in impelling forward the particles of air; and, conſequently, by increaſing their velocity will increaſe the intenſity of the ſound; and the ſurface alſo increaſing the number of points of impulſe, and of new propagations, will increaſe proportionally.

Of Echos.

This ſubject cannot be fully underſtood without reference to mathematical reaſonings, which we have endeavoured to avoid as much as poſſible: we can only, therefore, make a few obſervations in this place, referring the reader to Mr. Young's excellent work for a clear and full explanation. He ſhews that the uſual poſition of moſt writers, that ſound obſerves the law of all other reflexions; that is to ſay, that the angle of reflexion is equal to the angle of incidence, is erroneous; for in ſound every point of impulſe becomes a center, from which a new ſeries of pulſes are propagated in every angle whatſoever. The principles on which echos are founded are therefore theſe: 1. Every point againſt which the pulſes ſtrike becomes a center of a new ſeries of pulſes: 2. That ſound deſcribes equal ſpaces in equal times; therefore, when any ſound is propagated from a center, and it's pulſes ſtrike againſt a variety of obſtacles, if the ſum of the right lines drawn from that point to each of the obſtacles, and from each obſtacle to a ſecond point, be equal, then will the latter be a

point in which an echo can be heard. Thus, let A (*fig.* 11, *pl.* 4,) be the point from which the ſound is propagated in all directions, and let the pulſes ſtrike againſt the obſtacles C,D,E,F,G,H,I, each of theſe points becomes a new center of pulſes by the firſt principle; and therefore from each of them one ſeries of pulſes will paſs through the point B. Now, if the ſums of the right lines $\overline{AC+CB}$, $\overline{AD+DB}$, AE+EB, AG+GB, $\overline{AH+HB}$, $\overline{AI+IB}$, be all equal to each other, it is obvious that the pulſes propagated from A to theſe points, and again from theſe points to B, will all arrive at B at the ſame inſtant, according to the ſecond principle; and therefore, if the hearer be in that point, his ear will at the ſame inſtant be ſtruck by all theſe pulſes. Now it appears from experiment, the ear of an exerciſed muſician can only diſtinguiſh ſuch ſounds as follow one another at the rate of nine or ten in a ſecond, or any ſlower rate: and therefore for a diſtinct perception of the direct and reflected ſound, there ſhould intervene the interval of one-ninth of a ſecond; but in this time ſound deſcribes $\frac{1142}{9}$, or 127 feet nearly; and therefore unleſs the ſum of the lines drawn from each of the obſtacles to the points A and B, exceeds the interval A B by 127 feet, no echo will be heard at B. Since the ſeveral ſums of the lines drawn from the obſtacles to the points A and B, are of the ſame magnitude, it appears that the curve paſſing through all the points C, D, E, F, G, H, I, &c. will be an ellipſe: hence all the points of the obſtacles which produce an echo muſt lie in the ſurface of the oblong ſpheroid, generated by the revolution of this ellipſe round it's major axis. As there may be ſeveral ſuch ſpheroids of different magnitudes, it follows that there may be ſeveral different echos of the ſame original ſound: and as there may

happen

happen to be a greater number of reflecting points in the surface of an exterior spheroid than in that of an interior, a second or a third echo may be much more powerful than the first; provided that the superior number of reflecting points, that is, the superior number of reflected pulses propagated to the ear, be more than sufficient to compensate for the decay of sound which arises from it's being propagated through a greater space. This is finely illustrated in the celebrated echos at the lake of Killarney, in Kerry, where the first return of the sound is much inferior in strength to those that immediately succeed it.

It is not absolutely necessary that the reflecting points C, D, E, F, &c. producing an echo, should lie accurately in the periphery of an ellipse; for if the sums of the right lines $\overline{AC+CB}$, $\overline{AD+DB}$, &c. do not differ from each other by more than 127 feet, the pulses propagated from these points will not be distinguishable. However, the nearer these sums approach to equality, the more accurate will be the coincidence of the pulses, and consequently the echo will be the more distinct.

From what has been laid down it appears that, for the most powerful echo, the sounding body should be in one focus of the ellipse, which is the section of the echoing spheroid, and the hearer in the other: however, an echo may be heard in other situations, though not so favourably; as such a number of reflected pulses may arrive at the same time at the ear as may be sufficient to excite a distinct perception. Thus, a person often hears the echo of his own voice; but for this purpose he should stand at least 63 or 64 feet from the reflecting obstacle, according to what has been said before. At the common rate of speaking, we pronounce not above three syllables and an half,

that is, ſeven half ſyllables in a ſecond: therefore, that the echo may return juſt as ſoon as three ſyllables are expreſſed, twice the diſtance of the ſpeaker from the reflecting object muſt be equal to 1000 feet; for as ſound deſcribes 1142 feet in a ſecond, ſix-ſevenths of that ſpace, that is, 1000 feet nearly, will be deſcribed while ſix half, or three whole ſyllables are pronounced; that is, the ſpeaker muſt ſtand near 500 feet from the obſtacle: and in general, the diſtance of the ſpeaker from the echoing ſurface, for any number of ſyllables, muſt be equal to the ſeventh part of the product of 1142 feet multiplied by that number.

In churches we never hear a diſtinct echo of the voice, but a confuſed ſound when the ſpeaker utters his words too rapidly; becauſe the greateſt difference of diſtance between the direct and reflected courſes of ſuch a number of pulſes as would produce a diſtinct ſound, is never in any church equal to 127 feet, the limit of echos.

But though the firſt reflected pulſes may produce no echo, both on account of their being too few in number, and too rapid in their return to the ear; yet it is evident, that the reflecting ſurface may be ſo formed, as that the pulſes which come to the ear after two reflections or more, may, after having deſcribed 127 feet, or more, arrive at the ear in ſufficient numbers; and alſo, ſo nearly at the ſame inſtant as to produce an echo, though the diſtance of the reflecting ſurface from the ear be leſs than the limits of echo. This is confirmed by a ſingular echo in a grotto on the banks of the little brook called the Dinan, about two miles from Caſtlecomer, in the county of Kilkenny. As you enter the cave, and continue ſpeaking loud, no return of the voice is perceived; but on your arriving at a certain point, which is not above 14 or 15 feet from the reflecting ſurface, a very diſtinct

tinct echo is heard. Now this echo cannot arise from the first course of pulses that are reflected to the ear, because the breadth of the cave is so small that they would return too quickly to produce a distinct sensation from that of the original sound: it therefore is produced by those pulses which, after having been reflected several times from one side of the grotto to the other, and having run over a greater space than 127 feet, arrive at the ear in considerable numbers, and not more distant from each other in point of time than the ninth part of a second.

The following observations on the phenomena of sound, and the vibration of strings, which were communicated to me by a very ingenious philosopher, will be found to merit your attention.

The phenomena of sound and the vibration of strings have received much illustration from the skilful experiments, and accurate calculations of many judicious mathematicians; but the mode in which vibration is effected and continued in sonorous bodies, and propagated through elastic mediums, does not appear to have been properly attended to.

" To shew that sound is not propagated by undulations or waves, such as we see produced in water by throwing a stone therein, I shall first point out the insufficiency of the hypothesis, and afterwards indicate the mode in which I imagine sounds are propagated through the medium, and the sort of movement strings receive when in vibration.

" It is known from experiments that sound proceeds from a center spherically with equal velocities, whether the cause or vibration of the sonorous body be grave or acute, strong or weak. It is obvious that water, which may be considered as an incompressible fluid, cannot be undulated from a center spherically; as in this case the en-

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"It is known from experiments that sound proceeds from a center spherically with equal velocities, whether the cause or vibration of the sonorous body be grave or acute, strong or weak. It is obvious that water, which may be considered as an incompressible fluid, cannot be undulated from a center spherically; as in this case the en-

tire mafs muft be moved, from the nature of incompreffibility (and yet water will tranfmit found.) If it be granted that an incompreffible fluid cannot undulate from a center fpherically, but that an elaftic fluid may; we reply, that the phenomena prove found is not propagated by fuch undulations, though the medium may poffibly be fufceptible of them.

Let A (*fig.* 5, *pl.* 4,) reprefent a fonorous body producing the equal and fucceffive undulations, b, c, d, &c. from a center fpherically, it is evident they would continue *ad infinitum*, equal caufes producing equal effects, as the wave *n* is equal to the wave *b*, and the medium is the fame; confequently found fhould never decreafe, as an equal wave of the fame medium would ftrike the ear at *d* or at *m*, and produce equal found, which is contrary to fact. Let A be fuppofed to produce undulations decreafing in the inverfe ratio of the fquare of the diftance, the velocity of found would decreafe in that proportion; but this is alfo contrary to fact, for found is always uniform.

" It is plain, therefore, that the phenomena in either cafe do not correfpond with the hypothefis, which confequently cannot be true.

" Let us now fay by what means found is propagated or tranfmitted through the mediums proper for it's tranfmiffion.

" Sound proceeds progreffively through the air with an equal velocity, decreafing in force, if the medium be of equal denfity, in the inverfe ratio of the fquare of the diftance from the fonorous body. Now it is demonftrated that undulations or waves in the air would not produce the phenomena, as they would neceffarily produce equal force with equal velocity, or unequal velocity with unequal force: and as motion or force can only be tranfmitted from one body to another, by *direct motion*, or

or change of place, or by *rotatory motion* without change of place; and as direct motion is insufficient to explain the case, it remains to try whether the rotatory motion of the particles agrees better with the known phenomena."

"Before we proceed further, it will be necessary to say a few words on the movement of vibration in the string, or sonorous body. Let A B *(fig.* 7, *pl.* 4,) represent a musical string; place a bit of paper on the string *(fig.* 7, *pl.* 4,) and make it vibrate: the paper will *turn round* in the direction in which the string is struck till the vibration ceases. Now it is plain if the string *oscillated*, the paper would not turn round, but simply move from side to side with the string; and if the string moved from the center, as when you take a cord in your hand, the one end fast, and turn it round, it would be twisted, and naturally turn back again to get rid of the twist; and consequently would turn the cord back again, &c.

"But the cord only moves one way; the string, therefore, only moves one way, and that way is in a *spiral* direction, *(fig.* 8, *pl.* 4,) no other being proper to produce the effect. The force returning by means of a subtle medium, and the vibration decreasing in proportion to the density of the medium it vibrates in, as it naturally communicates more or less force, according to the number of particles it touches in a given time, as the string obviously *turns* in a spiral, and does not *return*; it is plain the force can only be kept up by a subtle medium: now, the string in turning *(fig.* 9, *pl.* 4,) when at *a*, strikes a particle of air *o*; and as it makes the circle a, b, before it strikes it again, that time is the measure of the vibration; each particle of air struck is necessarily turned round it's axis with a velocity proportioned to the stroke: a turns b, b turns b, b, c, &c. but as the number

of particles increaſe in the ratio of the ſquare of the diſtance, and the force is equally divided between the particles; their rotatory velocity decreaſes in that ratio, and conſequently their impulſion, or power to produce ſound; but their progreſſive velocity from A to d (*fig.* 10, *pl.* 4,) is undiminiſhed: for, although b has four times the velocity of c, and nine times that of d, yet b, c, and d employ equal time to communicate their unequal forces to the contiguous particles. Indeed, if we examine the nature of communicating force or motion from one body to another, you will probably find that ſolid bodies always *vibrate*, and that fluids always have a *rotatory* motion: for let us ſuppoſe an incompreſſible fluid with it's particles in contact, it is evident that a fluid could only communicate force or motion from one body to another by the entire motion of the intervening fluid, or by the rotation of it's particles: but as we have no idea that motion can be communicated but by motion, it ſeems difficult to conceive how a, can tranſmit force to b and c, without being itſelf firſt moved; and in this hypotheſis, a, can only have a rotatory motion with the entire a c; but as it is not demonſtrable that an incompreſſible fluid exiſts, we can only prove that an elaſtic fluid, where the particles may be ſuppoſed ſeparate, with or without the intervention of a ſubtle medium, tranſmits force by the rotatory motion of it's particles, from the inſufficiency of any other hypotheſis.

"Several vague and incorrect expreſſions have crept into the doctrine of ſounds; as, that ſound is propagated by vibrations in the air: now the air does not vibrate; for vibration means a courſe and recourſe in a given time, and belongs only to the ſonorous body; but the air propagates ſound progreſſively with an equable velocity, without

any

any return: thus, a, b, c, oooooooo *a* moves b, b moves c, &c. but c never moves b, nor b, a; and a remains at reſt till the ſonorous body returns to it, and gives it a freſh rotation; for if it were a movement of impulſion only, it would cauſe undulation; and as the waves would neceſſarily decreaſe, the velocity would decreaſe; and if the waves did not decreaſe the ſound would not decreaſe, as a ſimilar wave of the ſame air would give the ſame ſhock, and produce the ſame ſound; but the velocity of ſound does not decreaſe, and the force of ſound does decreaſe: ſound, therefore, cannot be propagated by impulſion only; and as we cannot imagine force to be communicated except by impulſion or rotation, rotation of the particles muſt be the mode by which air conveys ſound.

"That a ſtring makes it's vibrations by a ſpiral motion, will appear more evident when we conſider that the force has at once a progreſſive and rotatory motion: thus, let A B (*fig.* 6, *pl.* 4,) repreſent the ſtring of an harpſichord; ſtrike at B, the force paſſes from B to A, and as it moves along, turns the ſtring at the ſame time. No other than a ſpiral motion can produce at once progreſſion and rotation; and as the force continues ſome time in the ſtring without returning from A to B along the ſtring, it ſeems neceſſary to call in the aid of a ſubtil fluid to tranſmit the force from A to B."

Of Musical Sounds.

"There are few who have not felt the charms of muſic, and acknowledged it's expreſſion to be intelligible to the heart. It is a language of delightful ſenſations that is far more eloquent than words: it breathes to the ear the cleareſt intimations; but how it was learned, to what origin we owe

owe it, or what is the meaning of ſome of it's moſt affecting ſtrains, we know not.

"We feel plainly that muſic touches and gently agitates the agreeable and ſublime affections; that it wraps us in melancholy, and elevates in joy; that it diſſolves and inflames; that it melts us in tenderneſs, and rouſes to anger; but it's ſtrokes are ſo fine and delicate, that while it wounds it pleaſes. As the paſſions of individuals are more or leſs eaſily affected, ſo will their taſte of harmony proportionably vary. Muſic is a language directed to the paſſions; but the rudeſt paſſions put on a new nature, and become pleaſing in harmony. It awakens paſſions that we do not perceive in ordinary life. The moſt elevated ſenſations of muſic ariſe from a confuſed perception of ideal or viſionary beauty and rapture; which is ſufficiently perceivable to fire the imagination, but not clear enough to become an object of knowledge. The nobleſt charm of muſic, though real and affecting, ſeems too confuſed and fugacious to be collected into a diſtinct idea. Harmony is always underſtood by the crowd, and almoſt always miſtaken by muſicians; who are in general ſervile followers of the taſte of the mode; and who, having ſpent much time and pains in the practical part, lay a ſtreſs on the dexterity of hands, which yet have no real value, but as they ſerve to produce thoſe collections of ſound that move the paſſions."

True muſic is the tuning and modulation of the ſounds and expreſſions of nature, ſo as to excite anſwerable ſenſations and ſentiments within us. *Harmony* and *mind* are connatural; whatever beings partake of either, partake of both: hence it is, that *muſical ſounds* uttered by *human voices*, or iſſued from any muſical inſtrument of *man's contrivance*,

trivance, proceed from what is of *Divine origin*; and the force of them is felt only by what is of the same origin in others; namely, *harmony* and *mind*. Sound is nothing more than the subject matter of music: it is harmony which gives forms to this matter, and makes *sounds* to be *musical*; but proportion, harmony, regularity, and order, are *affections* of the percipient principle within us; from it they receive all their beauty, to it they owe all their reality.

The theory of musical sounds is too intricate and subtle to make a part of my plan of instructions; I shall, therefore, content myself with laying before you a few observations, merely to awaken your attention to this curious subject.

All motion is in time and measure; and as musical sounds proceed from motion, they must be the objects of mensuration. If they are measurable by numbers, there will be between those numbers a variety of relations; so that some, when compared with others, shall be rational, and others irrational; and these will denote the agreements or disagreements of sounds among themselves, which are called *consonances* and *dissonances*.

Two strings of equal length, tension, and thickness, by performing their vibrations together, will sound the same note, or be in *unison*. Two pipes of the same length and diameter will agree in the same manner. In the case of the string the air is struck by the body, and the sound is excited. In the case of the pipe the body is struck by the air; but as action and re-action are equal, the effect is the same in either case. If the pipe were carried forward against the air, as swiftly as the air is driven against the pipe, it would utter a sound, as when the air moves and the pipe is at rest.

Large instruments and long strings produce grave or deep tones; small instruments and short

ſtrings produce acute or high tones; in organ-pipes, for inſtance, in proportion to their length and dimenſions: this is alſo true in muſical ſtrings. If I take a muſical ſtring of any length, and divide it into two equal parts by a bridge in the middle, each half ſounds an octave, that is, eight notes higher than the tone of the whole ſtring: their vibrations relative to the whole ſtring are as 2 to 1; therefore, they perform the ſame number of vibrations in half the time; conſequently the octave coincides with the fundamental note at every ſecond vibration.

Hence you will obſerve, that it is the ſhorteſt ſtring of a harpſichord which makes the high notes; and that they gradually increaſe in length as you increaſe to the deepeſt note of the inſtrument, though there be black and white keys on the harpſichord, and each ſtrikes a different note, which are called by the firſt ſeven letters of the alphabet. If you begin with A, and ſtrike ſeven notes in ſucceſſion upwards or downwards, you will either way come again to A; they are not, indeed, the ſame notes as that with which you began, but they are octaves to it, vibrating the one in half, the other in double the time. Theſe ſeven notes are thoſe of a peal of bells: when there are eight, the ſmalleſt bell is an octave to the largeſt. To render their inſtruments more comprehenſive, muſicians have introduced intermediate notes called ſemi-tones; each half a tone higher than the note below it, and conſequently half a note lower than the note above. Theſe are the ſhort white keys on the harpſichord.

OF SYMPATHETIC SOUNDS.

A ſympathy is obſerved when muſical ſtrings are compared together; and when the ſame ſtring is compared with itſelf, the parts ſympathize with the

the whole. When one ſtring is ſtruck, another that is near it, and in concord with it, will anſwer it ſo that the ſound may be diſtinguiſhed by the ear, though ſomewhat obſcurely. When it cannot be heard, it's ſympathetic vibrations may be diſcovered by laying ſome light body on it, which will appear to be agitated, ſo as even to fall away from the ſtring: but if the ſame ſtring makes a diſcord with it's fellow, no motion will ariſe in it. This effect muſt be ſuppoſed to depend upon the undulation of the air; which being according to, or in a certain meaſure, excite correſponding vibrations in ſtrings that accord with them, but produce no effect in thoſe that contradict them: as the vibration of a ſtring produces ſound in the air, ſo ſound already excited, if of a proper meaſure, will produce vibrations in a ſtring.

There is ſomething ſtill more ſubtle than the coincidence between two different ſtrings in concord. Every ſingle ſtring carries it's own harmony with it. When a ſingle ſtring is ſounded, there are certain ſecondary and ſubordinate vibrations attending upon the primary; inſomuch, that it is queſtionable whether there is any ſuch thing as a ſolitary ſound in nature.

What ſhare ſoever man may ſeem to have in modifying, all that is found in this world to delight the ſenſes, is primarily the work of *God.* Wine is prepared by human labour, but it is given us in the grape by the Creator. The priſmatic glaſs is the work of art; but the glorious colours it exhibits to the eye are from *Him* who ſaid, *Let there be light.* Man is the contriver of muſical inſtruments, but the principles exciting harmony are in the elements of nature. The element of air was as certainly ordained to give us harmonious ſounds in due meaſure, as to give reſpiration to the lungs; it is ſo conſtituted as to make thouſands of

pulſes

pulſes at an invariable rate, by means of which the proportions and coincidences of muſical ſounds are preſerved.*

Muſic may be conſidered farther, as the work of God in the nature of man, who has enabled him to ſing as well as to ſpeak. The gift of ſpeech we cannot derive but from the Creator, and the gift of ſinging is from the ſame author. The faculty by which the voice forms muſical ſounds is as wonderful as the flexures of the organs of ſpeech in the articulation of words. The human pipe is of a ſmall diameter, and very ſhort, when compared with the pipes of an organ; yet it will diſtinctly give the ſame note with the pipe of an organ eight feet in length. The moveable operculum on the pipe of the human throat, which is imitated by the reed of the organ, has but a very ſmall range: yet, with the contraction and expanſion of the throat, it will utter a ſcale of ſeventeen degrees, and divide every whole tone into an hundred parts, which is ſuch a refinement on mechaniſm as exceeds all deſcription. Contrary to the opinion of ancient philoſophy, it has been demonſtrated by the late curious experiments of a very ingenious inquirer into the frame of man, in a neighbouring nation, to be partly flutal, and partly chordal: wherein the vibrating air, in it's various degrees of expiration, or propulſion from the lungs, ſerves as a bow, or as quills to ſtrike upon the chords. The correſpondent vibrations of the little chords have, by his diſſections, been made apparent to the eye, continuing as long as the ſound continues; the ſound dying away as the vibrations ceaſe. The cartilages and muſcles, which ſerve variouſly to extend, or to remit theſe chords, and thereby attenuate them, or increaſe their diameters, ſo as to

* Jones's Sermons, vol. ii. p. 160 to 163.

to render the voice either ſhriller or deeper, are a contrivance which almoſt ſurpaſſes wonder; eſpecially when we conſider the amazing ſubtlety, and nice adjuſtment of the machine in it's operation; that the whole difference of extenſion or contraction, within which the entire extent of the human voice is placed, through an almoſt infinite variety of notes, lies within the compaſs of two or three lines, or within the minute compaſs of a ſixth or fourth part of an inch. Thus you ſee that the works of God ſurpaſs the imitation, or even comprehenſion of human art; wonderfully made for the communication of ſocial pleaſure and moral improvement.

The ſame may be obſerved of the ear: if this were either more or leſs ſenſible, we ſhould never have had any idea of melody or harmony; for a ſtring and it's aliquot diviſions are as 1, $\frac{1}{2}$, $\frac{1}{3}$, $\frac{1}{14}$th, &c. and the number of vibrations in a given time are as the numbers 1, 2, 3, 4: conſequently, this ſeries of ſounds muſt contain all the poſſible varieties of intervals. If, therefore, every aliquot diviſion produced a ſenſible effect by it's vibration, we ſhould hear in every muſical ſtring an infinite variety of chords, diſſonant and conſonant, in ſharp and flat keys at the ſame time. Thus would all the charms of melody be deſtroyed, and where many muſical ſtrings were ſounding together, this confuſion of conſonance and diſſonance would be ſtill farther increaſed; and we ſhould, therefore, have been deprived of the perception of harmony.

You have here then another inſtance of the admirable ſkill with which the different parts in nature have been adapted to each other by their all-perfect Creator. In other caſes you have found him conſulting the welfare of his creatures; in the preſent inſtance you muſt infer that he has not been

been leſs attentive to our innocent gratifications: for had the human ear been endued with a leſs degree of ſenſibility than it is at preſent poſſeſſed of, it is evident that we ſhould have loſt much of the delightful effects of harmony; had it been endued with greater, we ſhould have had no perception either of melody or harmony; ſo that the human ear has the proper conſtruction that contributes moſt to the pleaſures of hearing.

I have now finiſhed one of the firſt ſubjects that I meant to explain, and have laid before you an account of the principal properties of our circumambient atmoſphere. Many things yet remain to be explained; one or two of theſe I ſhall ſlightly mention; others cannot be diſcuſſed till I treat on fire and elaſtic fluids.

The atmoſphere that ſurrounds our earth, contains a mixture of all the active and volatile parts of the habitable world; that is, of all vegetables, minerals, and animals: whatever perſpires, corrupts, or exhales, impregnates the air. By it's *perpetual oſcillation* air *continually operates* on all things that have life, whether animal or vegetable, keeping their fibres and veſſels in continual action, according as it's preſſure and elaſticity are varied by heat or cold, moiſture or dryneſs. By it's preſſure the parts of our bodies are kept compactly together, and the fluids prevented from burſting their veſſels: in the ſame manner with vegetables, without this preſſure, the internal air would eſcape, and deprive the juices of the agent that helps to drive them forward. So far from being injurious to us, this preſſure is our greateſt comforter and aſſiſtant: when the air is heavieſt our ſpirits are found to be the lighteſt; when the mercury is at it's greateſt height we are invigorated and enlivened, and are more alert than when the mercury is low and the atmoſphere light.

It

It is the particles of air and other corpuscles floating in the atmosphere, which form that noble and lovely blue canopy so magnificently arched over our heads: it is these which reflect those innumerable rays of light, which occasion the soft approaches to day and night, the morning dawn and evening twilight: it is these particles that form that enfeebled appearance which gives you the idea of visible distance; the objects that are near, glowing in lively colours, while those at a distance are circumfused in a blue mist, too faint to be called a cloud; but receding still further from you, they wholly disappear, and sink in the circumfluent ocean of air: it is here that the clouds, pendent lakes of water, are sustained, and float. The yielding atoms glide from you in the passive air while it is still; yet, if the storm blows, and the air in full tide rushes one way, it bears down houses and large forests; it sweeps the vast seas into mountains. However insensible the opposition of every single particle may be, and however irresistible the motion and force of a cannon ball that lays in dust the firmest castles and fortresses, yet is it's force in a few moments overcome and deadened by the numberless and successive opposition of the particles of the yielding air.

In the course of your philosophical pursuits, many arguments will occur, both from nature and experiment, which seem to prove that the element which surrounds us is not merely a mixture of air and fire, but one thing in kind, consisting of parts differing in degrees of subtlety, from the grossest to the most refined air; with a gradation so insensible, that we shall never be able to say where air ends and fire begins: as the light of the rainbow grows so dilute by degrees, that no line can be drawn between it's edge and the uncoloured sky. Yet, from the grossest air to the most intense fire,

 the

the progreſſion is ſo remote, that philoſophers have connected air and fire by the mediation of what they call a *ſubtil matter*, partaking of the nature of both.

Experiment and reaſon ſeem further to prove that light is the mediating ſubſtance between fire and air; it's two extremes are red and blue; one the colour of fire, the other of the air. The red rays are either fire, or would be ſuch under certain circumſtances: while the ſhades of blue vaniſh into air, or would be ſo if we could purſue them far enough; but when they ceaſe to be coloured, they ceaſe to be viſible.*

That air and fire are different conditions of the ſame elementary matter of the heavens, is ſo far from being a new opinion, that it is a doctrine of great antiquity. If air reſolves itſelf into fire, and fire by it's turn reverts to air, it ſeems nothing more than what is commonly obſerved in water, which aſſumes the ſolidity of ice, and coaleſces into the fleecy form of ſnow, or becomes rare and impalpable in vapour: under all theſe conditions, it is nothing but the one ſimple ſubſtance of water, to which it returns ſooner or later. When you affirm that a ſnow-ball and the water in a cauldron are of the ſame ſubſtance, who can deny it? A child who ſhould feel both, would not readily underſtand how this could be; and yet are we not all children in philoſophy? Various ſimilar inſtances may be pointed out, all tending to illuſtrate theſe notions.

But if the conſtitution of the air be agreeable to this analogy, we muſt conſider the matter of the heavens as one vaſt fluid, whoſe parts differ in magnitude; ſo that ſome will be ſtopped by the ſurfaces of bodies, while others more ſubtil paſs freely

* Jones's Phyſiological Diſquiſitions.

freely through their pores: thus ſome will be acting within, others without bodies; ſome will heat, others will cool them; ſome will compreſs, others will divide; and thus carry on the two great and univerſal effects of conſolidation and diſſolution, generation and corruption.*

Already I have obſerved to you how much theſe ſtudies tend to cheriſh and invigorate a taſte for true beauty and lovelineſs, a deſire to dwell on *truth*, *equity*, and *goodneſs:* by contemplating theſe objects, you will be inſpired with an admiration and love of them; admiration and love beget imitation firſt, and then ſimilitude. I have alſo obſerved to you that every effect in the *creation* of the world, or the *government* of it, ſhews the conſummate wiſdom of it's *Creator* and *Governor*. This wiſdom, indeed, is ſeldom ſeen but by thoſe who philoſophize, and are curious to ſearch and pry into the wondrous *frame* of every piece of Divine *workmanſhip;* and into the ſecret *ſprings*, and every complicated *movement* of the Divine *adminiſtration*.

The *wiſdom* ſhewn in any *work*, *operation*, or *energy*, whatever it may be, is diviſible into two kinds: one reſpecting the *end* or *deſign*, the other reſpecting the *means* by which the end or deſign is accompliſhed. Every end is *wiſe* in which ſome conſiderable good is intended to be produced; and that is the wiſeſt end in which the moſt and greateſt good is intended: all means are wiſe which have a *tendency* to produce their end; and thoſe are the wiſeſt means which are the *ſhorteſt* and *ſimpleſt*, and at the ſame time the moſt *efficacious* and *certain*.

Now, in that ſtupendous work, the fabric of the great world, or the external univerſe of things, you

* Jones's Phyſiological Diſquiſitions.

you will find every requisite to prove *that wisdom* the most *perfect* was the Creator of it: for if the world in which we live, this terraqueous globe, with it's surrounding atmosphere, and as much as we can see above it, be taken for a specimen of the whole, it will appear to you, on an accurate survey, that the *end* intended to be produced by the *creation*, was the *most good* possible; good to *every being* so formed as to be capable of enjoyment; and to the noblest of these created beings as *much* and as *great* good as it is possible for creatures to enjoy: the proof of this has already commenced, and will be continued through the course of this work. It is beyond human power to conceive a better contrivance for *good* than the *air* that surrounds our earth: it is this that makes way for the transmission of light, without which the faculty of seeing in all animals, would have been useless. It is this that provides for the ease and freedom of motion upon earth, without which life itself had been bestowed to little purpose. It is this which communicates sound, without which we could not have conveyed our thoughts to one another by the help of speech; not to speak of the pleasure which results from the harmony of different sounds. It is this that gives rise to the *wind*, which mixes and tempers the exhalations interspersed in the atmosphere, corrects the heat in the hotter climates, and carries the clouds from place to place, to distil the needful rain; which, descending in prolific showers and dews, makes the smiling earth teem with plenty and beauty.

It is this that is the breath of life in all sublunary creatures: it is owing to this that so many classes of creatures are able to wing their way through the aerial regions. The more you reflect upon every circumstance, the more you will be convinced, that our *benevolent Lord* and *God* could

not

not have better adapted this part of inanimate nature for the diffusion of good.

Air is a general agent, not only exerting it's own, but calling forth the qualities or powers of all bodies: nothing ferments, vegetates, or putrefies without air, which operates with all the virtues of the bodies included in it; that is, of all nature; there being no drug salutary or poisonous whose virtues are not breathed into the air.

I should here like to give you the opinions of the antients on the subject of air: the discussion would be interesting and instructive; but, as it would lead us too far, I must confine myself to those of *Hippocrates;* a man almost deified for his knowledge by those of his own time. He had enriched his mind from the experience of earlier times, and a diligent study of nature: "The element of *air* has," says he, "dominion over the human body, and is the principal source of all things that happen to it, whether good or bad. It's power and influence deserve well to be examined; for wind is no other than a current of air rolling along in impetuous waves, which are so violent as to tear up trees by the roots, raise the waters of the ocean into a storm, and overwhelm and sink the largest vessels to the bottom of the deep. Such, and so great is the power it exercises, though at the same time it is not an object of our senses, but manifest only to our reason. What are the effects to which air is not necessary? or in what place is it not present? All the space between the heaven and earth is filled with it. It is the cause both of winter and summer: in the winter it is condensed and cold; in the summer it is mild and serene. The sun, moon, and stars are directed by it in their courses; for air is the aliment of fire, and fire that is deprived of it becomes extinct; so that the sun itself has a per-

petual motion, by means of a pure and perennial air. The sea itself is impregnated with this element, because the inhabitants of the water cannot subsist without it: in a word, it sustains the moon in it's orbit, serves as a vehicle to the earth, and no place is void thereof."

Plato, the greatest and most amiable of the Greek philosophers, accounts for the animal functions from an *intertexture of air and fire* acting throughout the whole frame of the body. To *fire* he ascribes the office of expanding within, and acting through the body outwards; while the element of air compresses from without, and counteracts the force of the internal fire.

ON THE

NATURE AND PROPERTIES OF FIRE.

LECTURE VI.

AS it is one end of theſe Lectures to open and improve your underſtanding—to invigorate and expand the faculties of your mind—to exhibit a clear view of the beauties of creation—the properties of matter—the laws of motion—the powers and immortality of man—the ultimate intention of God in the production and preſervation of the univerſe; it will be proper to lay before you, from time to time, the nicer diſcriminations of truth and falſehood, which cannot be better effected than by collating the ſentiments of the wiſeſt and moſt experienced among mankind, and laying them before you.

Though Truth does not appear in the other departments of learning with that bold and irreſiſtible conviction with which it preſides in mathematical ſcience, it ſhines through them all, if not interrupted by prejudice, or perverted by error, with a clear and uſeful, though inferior ſtrength: and as it is not neceſſary for his general ſafety or convenience that the traveller ſhould always enjoy the heat and ſplendor of a mid-day ſun, whilſt he can purſue his journey with more pleaſure and accommodation under the weaker influence of the morning or evening ray, ſo it is not requiſite for the various concerns and purpoſes of

life, that men ſhould be led by truth of the moſt redundant brightneſs.*

On the contrary, it is in every view more uſeful and expedient for us, ſituated and circumſtanced as we are, that *Providence* has left us in the confines of much darkneſs, to act and move under the ſhades of weak, but ſufficient evidence: ſuch is the evidence we are obliged to reſort to in natural philoſophy.

To know the inherent powers and properties, qualities, attributes, motions, operations, cauſes, and effects of thoſe *bodies* with which we are by nature every where ſurrounded; which are perpetually ſoliciting the external ſenſes, and with whoſe uſes we are immediately concerned; conſtitute the various and extenſive field of PHYSICS or NATURAL PHILOSOPHY.

OF PHYSICAL PRINCIPLES.

The *evidence of the external ſenſes* is obviouſly the *primary principle* from which all phyſical knowledge is derived.

But whereas nature begins with *cauſes*, which after a variety of changes produce *effects*, the ſenſes open upon the *effects*, and from them, through the ſlow and painful road of experiment and obſervation, aſcend to *cauſes*.

Man appears upon the ſtage of this material ſyſtem as upon a viſionary theatre, in which he looks only upon the exterior of things, as the eye upon a flower that is full blown; or upon an inſect in all the pride and beauty of it's colours, without obſerving immediately the *different ſtages* through which they have paſſed, the *different forms* they have aſſumed, the *different changes* they have undergone;

* Tatham's Scale and Chart of Truth, vol. 1. p. 124, &c. a work which I moſt earneſtly recommend to the peruſal of all philoſophers.

dergone; and without deſcending to the *ſeeds* and *principles* from which they ſpring, and which, upon examination, will be found totally different both in form and colour. In like manner are the *ſenſes*, the ultimate criteria of all phyſical knowledge, liable to be impoſed upon and deceived in regard to the qualities and cauſes, the powers and operations of PHYSICAL BODIES.

The *ſenſes* are therefore to be aſſiſted by *obſervations* taken with diligence and circumſpection; and to be undeceived by different *analyſes*, which diveſt nature of her external and compounded form, and lay open her internal mechaniſm and conſtruction: their errors and miſconceptions are to be rectified by the uſe of *experiments* of different kinds, which penetrate her inmoſt receſſes, and deſcend to her remoteſt cauſes. By the application of ſuch aſſiſtance they are enabled, but not without difficulty, to leave behind the *fallacious*, to paſs from *one appearance to another*, and, as far as human ſearch can go, to judge of the *realities* of things.

The information which the ſenſes give us, as Lord *Bacon*, the great friend and father of philoſophers, has obſerved, is to be examined and corrected by various methods; for though they deceive us on all occaſions, they themſelves diſcover the errors into which they lead: but, whereas the errors lie immediately before us, the indications of them are to be ſought at a great diſtance.

The ſenſes are ſubject to a two-fold defect; they either *deſert*, or elſe *deceive* us. Many ſubjects *elude* their cognizance, however well they may be diſpoſed and free from impediment; either from the tenacity of the whole object, or the extreme minuteneſs of it's parts; from the diſtance of it's ſituation, the ſlowneſs or velocity of it's motion, it's familiarity to the eye, and from many other

other causes. And again, where they fully apprehend their object, they are not to be securely relied upon; for the testimony and information of the senses depend on the analogy and constitution of man, and not on those of the universe; so that to say *that sense is the adequate measure or competent judge of things*, is an assertion founded in mistake.

To obviate the imperfections of sense, philosophers are under the necessity, by much labour and attention, of calling in aid from every quarter, in order to supply the deficiencies, where the senses fail us; and also to regulate and rectify them where they vary in themselves. This is effected not so much by the use of instruments as by the help of experiments; for experiments are more penetrating and subtil than the senses, even when assisted by instruments of the most exquisite contrivance. I mean," says Lord BACON, for he is still speaking to you, " such experiments as are ingeniously invented, and applied with skill and address, to the elucidation of every thing which is the subject of inquiry.

Philosophers do not therefore rely upon the perception of the senses, immediately applied as in their proper and common exercise, but bring the matter of judging to this issue: That the senses judge of experiments, and experiments of things: thus experiments are in fact as the religious guardians of the senses, from which every thing in sound philosophy is originally derived, and the skilful interpreter of their oracles; so that whilst others only pretend, *true philosophers* in reality cultivate and support the EVIDENCE OF SENSE.

It may, therefore, be laid down as a maxim, " That no *physical effect* is really explained or understood, unless it be deduced from a physical cause; the existence and operation of which can be

be experimentally demonſtrated." Men have no right to aſſume the character of lawgivers to the works of God, but muſt be content to borrow from them *all the laws of philoſophy.*

I ſhall hereafter endeavour to explain to you the nature of *phyſical reaſoning*, and ſhew you how the philoſopher is conducted by a ſlow, but ſteady pace, in the rational inveſtigation of the *general cauſes* of phyſical truth: my preſent buſineſs will be to treat of the wonderful element of FIRE; an agent concerned in almoſt every operation in life, and every phenomenon in nature; and you may boldly aſſert, that that ſyſtem of natural philoſophy which does not conſider the agency of fire in it's explanation of phenomena, is not founded on truth.

OF FIRE.

Fire is an agent of ſuch importance toward the government of the natural world, and of ſuch uſe in all the concerns of life, that it has always attracted the notice of mankind, and driven them into various ſpeculations. We find, accordingly, that the ancient heathens not only admitted it into their philoſophy, filling the univerſe with it's ſubſtance, and deducing therefrom all the greateſt effects in nature; but they were ſo ſtruck with it's power and uſe in the world, that they paid to fire divine honours.

Notwithſtanding it's celebrity among the ancients, and the univerſality of it's agency in nature, very different opinions have been held by the moderns concerning it; ſome contending it it was incorporeal; others diſputing whether fire in itſelf is truly a being like water, air, and earth, or an adventitious and acceſſory property reſulting from the inteſtine motion of the inſenſible

insensible particles of matter; it will be necessary, therefore, to prove to you the materiality and reality of fire as a distinct being.

The far greater part of those who have considered the subject, believe fire to be a subtil, active, and elastic fluid, universally disseminated through the universe, penetrating all bodies with more or less facility; having a constant tendency to diffuse itself uniformly, so as to maintain an equilibrium; dilating the several substances it penetrates, and making them assume the state of fluidity, and afterwards that of vapour. *Whenever you perceive a number of qualities always existing together, you are warranted to conclude that there is some substance which produces those qualities.*

FIRE A REAL AND MATERIAL SUBSTANCE.

Fire can drive out other matter from any given space; and certainly that which can expel other bodies, and take the place of them, must itself be body. If the ball of a thermometrical tube be filled with air, spirits, or mercury, fire applied underneath will expel them all in their turns, which it cannot do but in virtue of it's own proper extension; and if it be extended, it is a bodily substance.

Whatever occupies space, and resists the touch, we have a right to call a material substance, whether we can *see* it, and *weigh* it, or not: thus air, which is *invisible*, and not very easily *ponderable*, is universally allowed to be a *substance*, and *not a quality*.

Light is an emanation of fire; the decomposition of the rays of light proves their materiality: what is light on the surface of a burning-glass, is fire at it's focus; whatever, therefore, proves the materiality of light is applicable to fire.

A fluid,

A fluid, ſubject to the like laws with the elaſtic air, muſt be as material as the air is. Fire, in common with air, is ſubject to be confined by an incumbent preſſure, and releaſed when that preſſure is withdrawn. Fire would make water boil much ſooner if it were not reſiſted by the preſſure of the atmoſphere on it's ſurface; and therefore it boils, as you have ſeen, with a very low degree of heat in the vacuum of an air-pump.

Fire evaporates alſo from an heated liquor more *ſlowly*, when *counteracted* by the preſſure of the air: thus, if two equal veſſels of water equally heated be ſet to cool, one under the exhauſted receiver of an air-pump, the other in the open air, the water under the receiver will cool ſooneſt: thus proving that fire is confined by an incumbent preſſure, and that it evaporates with greater freedom where there is leſs reſiſtance.

Proofs multiply on proofs to ſhew that fire is a material ſubſtance; for, like any actual ſubſtantial fluid, it may be *transferred* with different circumſtances, from one parcel of matter to another. If you add any quantity of hot water to the ſame quantity of quickſilver, of the ſame temperature with the atmoſphere, the water will communicate about twice as much heat to the quickſilver, as the quickſilver of the ſame heat would give to water as cool as the quickſilver in the firſt inſtance. This ſhews that fire is not the production of motion in the ſolid parts of matter; becauſe in that caſe the heavier particles of quickſilver would communicate more motion to the parts of water, than the parts of water, which are ſo much lighter, and have conſequently leſs momentum, could communicate to the quickſilver; whereas the effect of the heated water on mercury is twice as great as the effect of the heated quickſilver on the water. This neceſſarily implies a *transfuſion* of

ſome

ſome *matter* or *element* from one of the bodies into the other; and is inexplicable, upon the ſuppoſition that the particles are expanded by an innate repulſion, or any *unſubſtantial* quality; for how can quality be poured out like a liquor from one veſſel to another? or move like a river with different degrees of force, through channels of different breadths, as is plainly here the caſe with fire?*

Put a piece of iron or copper into a glaſs veſſel containing *aqua fortis;* if it works tolerably well, place the phial under a receiver, and exhauſt the air; it will then work with more violence; ſo much ſo, that if the air were exhauſted to an high degree, it might poſſibly take fire and explode. While it is boiling with vehemence, drop it into a veſſel of cold water (previouſly placed on the plate of the pump,) which will very ſoon ſo check the operation, that the *aqua fortis* will not work with the ſame violence ſo long as it is ſurrounded by the water. That the agent in this caſe is fire, appears very plainly, and that the *motion does not make the heat*, but that the *fire and heat occaſion the motion;* becauſe when the air, the natural antagoniſt of fire, is removed, the fire acts more freely. That the water applied externally ſhould check the fire, is very natural, if it be conſidered as a fluid; but no reaſon can be given why it ſhould check the operation, upon any other principle.

Nothing can be more ſtrange than to imagine motion can impart a property which it has not in itſelf: what kind of connection is there between the ideas of burning, and motion of any ſort? or how can motion account for any thing but motion? Imagine all kinds if you pleaſe; let them begin how you will, and take as many different directions

* Jones's Eſſay on the Principles of Natural Philoſophy.

tions in all their different particles—will this convey to your mind the idea of heat, light, or fire? Had you never felt the effects of fire, though you had seen the intestine motions of all the particles of the globe, do you conceive these motions would have given you the idea of heat or light?

Motion may disengage fire from bodies, or it may give it a particular direction, in which it may have a more sensible effect; but motion does not *create* fire. Motion may render things sensible, which it does not create or cause; and it may dispose them to act so as they would not have acted while at rest. We do not perceive the existence of air when there is a perfect calm; but when the air is put in motion, we perceive it: the motion does in this case all that the motion does in the other; it does not create what we perceive, though it renders it sensible. There was fire in the wood, and there was air in the field, though we did not perceive either while at rest: the rubbing two pieces of wood does not create fire, any more than the blowing of the wind creates air: motion only renders both perceptible; they both existed, although unseen and imperceptible to our senses.

Among the inconceivable and incredible mysteries that philosophy propounds, we may consider that which intimates the possibility of fire being nothing else but an intense vibratory motion of the particles of an heated or ignited body. In the hottest bodies we cannot be made sensible of vibration existing among their particles, while *certain sounds* will cause the most solid substances to *vibrate perceptibly*, without producing any heat.

That fire cannot be caused by any mechanical motion we can impress, is evident; because on mechanical principles the effect must always be proportionable to it's cause: in the case of fire

the effect very far exceeds the caufe, fuppofing the latter to be only a *mechanical percuffion*, as in the cafe of hammering iron till it be red-hot. We allow that by a few ftrokes of an hammer the iron will be put into motion, and heat will be produced; but if you direct this motion of thefe particles upon another body whofe parts are at reft, thefe will refift the communication from the former, in proportion to their *vis inertiæ*, and the cohefion of their parts. No reafoning upon mechanical principles can fhew why motion fhould increafe and multiply itfelf without end, as we fee fire do: befides, motion and vibration are *effects*, for matter will not begin to move itfelf: and further, thofe that have adopted the hypothefis of motion, *have never proved the motion for which they contended*: if granted, the phenomena could not be explained by it. If heat depended on motion, it would immediately pafs through an elaftic body; but it paffes through them flow, like a fluid: if it depended on vibration, it ought to be communicated from a given vibration, in proportion to the quantity of matter; but this is contrary to facts.—When we fee a fmall fpark gradually fet a large city in a blaze, it is impoffible to fuppofe that there is no more motion in all the parts of the city thus on fire together, than there was in the firft little fpark that began the fire; or that there is no more power or force in this fire, than in the fcarce diftinguifhable fpark by which it began. Further, the laws of the communication of fire are not analogous to the laws of motion; and nothing is lefs known, or more difficult to be known, than the progreffion and communication of fire in fyftems of bodies of unequal temperature.

In whatever way you examine nature, whether you begin with it as it ftands to the reafon, and then divide it by the imagination into all it's various

modifications; or whether you begin with the most general properties as they appear to the ſenſes, and then compound them into all the variety of nature, ſtill you will find that fire has the ſame pretenſions to reality with air, earth, and water.

How came it then that motion was ever aſſigned as the cauſe of fire? It ſeems to have ariſen from our being apt to conſider what we ſee immediately precede any thing, as the cauſe thereof: hence, perhaps, Bacon, Deſcartes, and Newton, having obſerved that heat followed the friction of two dried bodies rubbed together; that a cord caught fire by being rubbed againſt hard ſubſtances; and that a piece of iron might be beaten red-hot; were inclined to imagine that this motion was the cauſe which generated the heat; though a perſon who had never ſeen thoſe experiments, but who had obſerved that *motion* of ſome kind or other had been *always* produced in *all matter* upon the application of fire, would certainly have concluded the contrary—that motion was cauſed by fire: and when he found that heat is very often by no means the reſult of motion, but produces cold, he could not but infer the reality of the exiſtence of fire; which never fails to produce motion, in oppoſition to motion being the cauſe of fire, which is at beſt but a partial cauſe.

That ſpecies of falſe reaſoning which proceeds from a few particulars to a general concluſion, ſteals into the mind ſo imperceptibly, that men can hardly be too much on their guard againſt it. Conſidered in it's own nature, nothing can be more obvious than that a propoſition, which may be true in a particular inſtance, may not be ſo invariably; and that, therefore, two ſuch propoſitions ſhould never be confounded together as if they were ſynonymous: had this been ſufficiently

attended to, motion would never have been considered as the origin of fire.

The difficulty that has so long attended the acknowledging the reality and elementary existence of fire, has also arisen from the implicit credit we are apt to give to the opinions of very great men. A man of superior genius, who has distinguished himself by new discoveries, more extensive reasoning, or more accurately investigating truth, naturally gains an ascendancy over the minds of others, which spreads a sanction on his mistakes: it becomes a kind of sacrilege to examine even his conjectures; and time only, which lessens all other reverence, must wear off that which we have conceived for him, before mankind can acquiesce in his being fallible: nothing has been so eminently detrimental to the progress of science, as a blind and servile deference to the authority of great names.

As new terms have within these few years been adopted by the writers who have treated on fire, it will be necessary, before we proceed, to give you some account of them. By the word *fire* in these Lectures, I mean that very subtil fluid which is the *cause of heat*, and by which bodies are expanded, fluids raised into vapour, solid bodies rendered fluid, &c. Modern French writers, for the same purpose, use the terms *igneous fluid*, *matter of heat*, and lately *caloric*. Some English writers have used the word *heat* in the same sense; thus confounding the cause with the effect. Heat, properly speaking, is that sensation which the presence of fire occasions in an animate body: the state of an inanimate body, when it contains fire, is also distinguished by this word; for we say, the heat of red-hot iron. We ought always by the word *heat* to understand the *effect of fire*, or fire

fire acting in a certain manner, rather than the element itself which may exist in substances actually cold to the senses.

Dr. Irvine and Dr. Crawford use the term *absolute heat* for that power or element which, when it is present to a certain degree, excites in all animals the sensation of heat: in this sense *absolute heat*, and the element of fire, have the same signification. *Fire*, as having a relation to the effects it produces, and by which it is known and measured, is called by Dr. Crawford *relative heat*.

GENERAL IDEAS OF FIRE.

The great Boerhaave maintained that fire was a fluid universally diffused, and equally present in the frozen regions as in a glass-house furnace; only in the latter it is put in action, and rendered more evident to our senses; if brought into action it's existence would be as demonstrable in the coldest part of the world as in the furnace; all bodies contain it: it is in the earth we inhabit and the food which nourishes us; we ourselves are filled with it. Although it is capable of destroying and consuming all things; yet as it is incapable of combustion without another substance, it is so far from being prejudicial to us, that it forms an essential part of our animal life: it constitutes a portion of the fluid we breathe, the only part which contributes to support animal heat.

The far greater part of modern philosophers coincide in this respect with Boerhaave: to enumerate their names would be to fill pages; suffice it therefore to name a few: Jones, Lavoisier, Black, Crawford, De Luc, Pictet, De Saussure. Hear Mr. Lavoisier speak for himself: "I consider our earth," says he, "as every where surrounded by a very subtil fluid, which penetrates without exception all the bodies which compose it." This

fluid he calls caloric, we call it fire: it tends always to put itſelf in equilibrium in all bodies; but it does not penetrate all with equal facility. Laſtly, this fluid is ſometimes in a ſtate of liberty, ſometimes in a fixed form, and combined with bodies.

This opinion on the exiſtence of fire is far from being new; it is that of the greateſt number of ancient philoſophers: "I ſhall, therefore," ſays he, "diſpenſe with relating the facts on which it is founded; but if I ſhew that it always accords with the phenomena, and that it explains every thing that happens in philoſophical and chemical experiments, it will be almoſt giving demonſtration to opinion. Indeed this opinion ſeems too conformable to the courſe of facts, and the ſimplicity of nature, to be conſidered only as an hypotheſis."

PENETRATION OF FIRE.

Fire penetrates all bodies, even the hardeſt, being equalled therein only by the magnetic fluid; every thing around and about you confirms this truth; it may be eaſily alſo illuſtrated by experiment: cover this thermometer (which I have already told you is an inſtrument to meaſure the degrees of heat) with glaſs; apply any heated ſubſtance to the outſide of the glaſs, and it will raiſe the fluid in the thermometer: the ſame will take place if it be incloſed by a metallic caſe, or a caſe of any materials whatſoever: this could not happen unleſs fire penetrated through the materials.

A thermometer ſuſpended in an exhauſted receiver will ſhew the ſame degree as one in the open air; for the fire which is diffuſed through the atmoſphere, is alſo diffuſed through what we call a vacuum. Sir Iſaac Newton had, indeed, long

long ago ſhewn that heat was conveyed by a medium more ſubtil than common air; becauſe two thermometers, one placed in the vacuum of an air-pump, and the other in the open air, but at an equal diſtance from the fire, will ſhew an equal degree of heat nearly at the ſame time. Had he purſued this thought, he would have, no doubt, concluded that fire is preſent in all places, and that it is active where there is no terreſtrial matter as where it abounded.

TENDENCY OF FIRE TO AN EQUILIBRIUM.

One of the moſt conſtant characters of fire is a continual tendency to equilibrium, or to flow from a warmer to a colder body; to iſſue from thoſe parts where it is leaſt reſiſted, till the reſiſtance becomes uniform; communicating the ſuperabundant fire to all ſurrounding bodies, till they attain the ſame temperature. In this point of view fire ſeems to be reſtrained only by itſelf. To obſerve the fluctuation of fire from one body to another, till they all acquire the ſame temperature, place in a room where the ſun does not ſhine a variety of ſubſtances; as wood, feathers, iron, &c. of different temperatures: let a thermometer be applied cloſe to each of them, and the fire in the hotteſt will diffuſe itſelf among thoſe that are heated to a leſs degree; and it's fluctuation from one to another will be evident by the thermometer, till they all acquire the temperature of the room: this is, among many other phenomena, one that cannot be conceived without admitting fire to be a fluid, paſſing from one body to the other till it is equally diffuſed.

OF THE DISTRIBUTION OF FIRE, AND OF THE SUBSTANCES WHICH CONDUCT HEAT.

It does not appear that different degrees of fire can penetrate all bodies with equal ſorces in equal times; or, in other words, the power of tranſmitting heat is different in different bodies; ſome conducting it more readily than others: thus, if you hold one end of this metallic rod in your hand, and put the other in the fire, it will ſoon become too hot to hold, though it is three feet long; but one end of this glaſs rod, which is conſiderably ſhorter, may be held without any inconvenience, while the other end is red-hot and melting. Again, here are ſeveral metallic rods, each of which is covered with a thin coat of wax: I plunge the ends of theſe into melted lead, and you perceive that the coat of wax melts ſooner on ſome than on others; which proves that ſome metals tranſmit fire more readily than others: in more general terms, *thoſe bodies, whoſe temperatures are ſooneſt altered, are ſaid to be the beſt conductors of fire.*

The difference in the ſpaces of time in which fire penetrates different bodies, and finally acquiring the ſame temperature, may depend on their peculiar powers or faculty of retaining fire; this faculty has been called their *capacity*. The greater this power is in any body, the greater the quantity of fire that will be accumulated therein before the equilibrium reſulting from that accumulation takes place; or, in other words, before it can exert the ſame expanſive force outwards; conſequently when this equilibrium is attained, though there may be an equal expanſive force exerted, and therefore an equal degree of heat indicated by the thermometer, it does not follow that there is an equal accumulation of fire in the ſeveral bodies.

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To illuſtrate this principle, let us plunge into a baſon of water at the ſame inſtant a pound of dried ſpunge, a pound of blotting-paper, and a pound of ſome porous wood: at the expiration of a certain time theſe ſubſtances will be equally wet, and will have imbibed all the water they are capable of retaining. The blotting-paper, as being the moſt permeable by the water, will be the firſt penetrated thereby; it will not penetrate the ſpunge ſo ſoon: 1ſt, Becauſe it is not ſo permeable by water as the blotting-paper: 2dly, Becauſe it has a greater capacity of imbibing water, and will conſequently require more time to be ſaturated than the paper: laſtly, The wood will require a longer time to be fully moiſtened, although it has leſs capacity, being leſs permeable to water than the other two ſubſtances.

When you take them out of the water, they will be apparently wetted in the ſame degree, as well externally as internally; but they will contain very unequal quantities of water. The circumſtances are nearly the ſame with reſpect to ſubſtances of equal maſſes, and different natures plunged in an atmoſphere of fire.

If we could apply an hygrometer to thoſe ſubſtances the moment they were taken out of the water, it would indicate nothing more than that they were equally humid; but would leave us ignorant of the quantities of water they contained. In like manner the thermometer applied to different ſubſtances heated to the ſame degree, will only ſhew that the fire has an equal expanſive force in each of them, but would give us no information as to the abſolute or relative quantities of fire which produce this expanſion.

You will find heat greatly retarded by cork, and ſtill more by feathers and wool, and other ſoft ſpungy ſubſtances; perhaps, becauſe there is leſs

contact of parts. Flannel, and feather-beds are considered as warm, but they have no heat; for they keep bodies (as ice, &c.) cool better than other substances: they hinder heat from evaporating, as their interstices are filled with air; being slow either in transmitting or parting with fire; they are proper for preserving and retaining the heat of our bodies, and thus keeping us warm. Snow being of a soft spungy texture, keeps the ground warmer than the freezing point; but this is warm, compared with the intense cold felt in several climates, frequently 32° below frost. Now, the freezing point is as much warmer than this, as the weather in our summer is than that of frost: it is common in Siberia to see the thermometer 150° below the point of congelation.

Fluids convey fire very fast; air cools bodies very fast: this may depend upon the expansibility which air undergoes from fire, which occasions a continual change of it's particles: thus if you expose a hot body to the air to cool, the air in contact therewith expands and becomes lighter, and is consequently driven upwards; and thus there is a constant accession of fresh air to the body. If you place the body between the sunshine and the wall, you will see the air rising like an undulating vapour upon the wall: you see it, because the vapour turns those rays of light aside which pass through it; and consequently the wall is less illuminated in those parts than the rest; and you therefore perceive the shadow for the same reason that you see the shadow of smoke. This causes objects, when viewed through the rarified air of a heated field, to seem to change place, and tremble when the sun shines upon it.

It is owing to this evaporation upwards that iron or any other substance will heat a body held over it sooner than under it; but if a piece of iron

is placed under a receiver, the bottom is hotteſt, as being neareſt in contact: hence the cold obſerved at ſea upon approaching mountains of ice; the cold air being condenſed falls down the ſides of the ice, and floats along the ſurface of the ſea. When a veſſel of water is placed over a fire, the lower parts of the water are expanded and rendered lighter thereby, and of courſe are driven to the top by the weightier and colder parts which deſcend to the bottom, and thus there is a continual circulation from the under to the upper part of the veſſel.

From the nature of fluids deep lakes of water ſeldom freeze in winter. The cold air, by ruſhing over the ſurface, will render the top weightier, which will ſink, and it's place be ſupplied with a warmer portion from below, which in it's turn will alſo be cooled: and the air has the whole heat of the water to carry away, which is often not done during a whole winter. Hence the remarkable temperature upon the ocean, and upon iſlands, when compared with continents in the ſame degree of latitude.

From Sir Benjamin Thompſon's experiments it appears, that of the different ſubſtances uſed in clothing, hare's-fur and eider-down are the warmeſt: after theſe come beaver's-fur, raw ſilk, ſheep's-wool, cotton-wool; and laſtly, lint, or the ſcrapings of fine linen. He alſo found that the air which occupies the interſtices of bodies, made uſe of for covering, acts a very important part in the operation of confining heat, which is ſtill further aſſiſted by the fineneſs and equal diſtribution of the ſubſtances made uſe of to form a covering for that purpoſe.

In furs the air interpoſed among it's particles is ſo engaged there as not to be driven away by the heat communicated thereto by the animal body;

not

not being eaſily *diſplaced,* it becomes a barrier to defend the animal body from the external cold.

Hence it appears why thoſe ſkins are warmeſt which have the fineſt, longeſt, and thickeſt furs; and how the furs of the beaver, otter, and other like quadrupeds which live much in water, and the feathers of water-fowls, are capable of confining the heat of thoſe animals in winter, notwithſtanding the coldneſs and conducting power of the water in which they ſwim.

Bears, hares, and other animals, inhabitants of cold climates, which do not often take water, have their fur much thicker upon their backs than their bellies. As the heated air would more naturally riſe upwards, and eſcape from the back, *Providence* wiſely guarded againſt this evil by increaſing the obſtructions in thoſe parts, and thereby confining it to the body of the animal.

The ſnows which cover the ſurface of the earth in winter in high latitudes, are doubtleſs deſigned by an ALL-PROVIDENT CREATOR as a garment to defend it againſt the piercing winds from the polar regions, which prevail during the cold ſeaſon.

Theſe winds, notwithſtanding the vaſt tracts of continent they paſs over, retain their ſharpneſs as long as the ground they go over is covered with ſnow; and it is not till they meet with the ocean that they acquire that heat which the ſnow prevents their obtaining from the earth, to take off the edge of their coldneſs.

There is no property of fire more generally known, or better underſtood, than it's diſpoſition to paſs from one body to another. If, as I have obſerved to you, a thouſand different *inanimate* bodies be brought together in a place where there is no poſitive cauſe of heat, the heat will immediately begin to flow from the hotter to the colder bodies,

bodies, till all become of one temperature, or till there is what ſome philoſophers call an equilibrium of heat.

But this is by no means the caſe with reſpect to animated matter; for, whatever be the degree of heat peculiar to individual animals, they preſerve it ſtable and unchanged in every temperature, provided that it be not altogether incompatible with life or health. Thus we find that the human body is not only capable of ſupporting, in certain circumſtances, without any material changes, a degree of heat in which the thermometer riſes conſiderably above the degree of boiling water;* but likewiſe that it maintains it's uſual temperature, whilſt the ſurrounding medium is ſeveral degrees below the point of congelation.

It is therefore evident that animals neither receive their heat from the bodies around them, nor ſuffer, from the influence of external circumſtances, any material alterations in that heat which is peculiar to their nature. This general fact is further elucidated and evinced by many late, accurate, and well-authenticated obſervations; which ſhew that the degree of heat, in the ſame genus or ſpecies of the more perfect animals, continues very uniformly the ſame, whether they be environed by mountains of ſnow in the neighbourhood of the pole, or expoſed to a vertical ſun in the ſultry regions of the torrid zone.

The ſtability and uniformity of animal heat, under ſuch a diſparity of external circumſtances, and ſo vaſt a latitude in the temperature of the ambient air, leave no room to doubt that the living body is furniſhed with a peculiar mechaniſm, or power of generating, ſupporting, and regulating it's own temperature; and that this is ſo adapted to the circumſtances of it's œconomy, or dependent

* Phil. Tranſ. vol. lxv.

dent upon them, that whatever be the heat of the atmoſphere, it will have very little influence either in diminiſhing or increaſing that of the animal.

OF THE DILATATION OF BODIES BY FIRE.

Fire never ceaſes to be fluid, unleſs when in a ſtate of combination with other bodies; it is alſo a principal cauſe of the fluid ſtate of other bodies. Fire, when agitated with that motion which is manifeſted by heat, always acts as if it wanted more room; and this in ſuch a wonderful manner, as if every particle was a radiant point or center.

The particles of a ſolid body, when heated to a certain degree, recede from each other: allow it to cool, the particles will approach, each in the ſame proportion in which they receded; and the body will return to it's former ſtate by the ſame degrees of expanſion, by which in the firſt inſtance it was extended.

This expanſion of bodies by fire may be deemed univerſal; there ſeems ſcarce any exception, but in thoſe bodies whoſe parts are brought nearer together, becauſe a fluid contained within them is driven out.

The firſt change that happens to any body when expoſed to the action of fire, is the rarifaction of it's whole maſs, and an augmentation of it's bulk.

Before I proceed, it will be neceſſary to notice a diſtinction of fire into two ſtates, *liberated* and *combined*, to be more fully conſidered hereafter. Liberated fire is that we are now concerned with; for by this ſtate is meant fire in action, producing the ſenſation of heat in animal bodies, and dilating the dimenſions of all ſubſtances; hence it is alſo often called *manifeſted*, or *thermometric fire*.

The intenſity of heat is meaſured by the quantity of free fire, or fire in action; for though we cannot

cannot determine the quantity, we can eſtimate it's action on bodies by the degree of their dilatation.

This dilatation is the moſt general indication of the preſence of fire. To appreciate this philoſophers uſe inſtruments called *thermometers;* in which a ſubſtance is always employed, whoſe volume augments as proportionably as poſſible to the increaſe of heat. The conſtruction of theſe inſtruments will be the ſubject of future diſcuſſion; it is ſufficient to inform you at preſent, that by the riſe of a fluid in a tube, we obtain a meaſure ſufficiently exact, of the increaſe or diminution of active fire. Leaving theſe, I proceed to conſider the expanſion of metals.

Metallic ſubſtances, with whoſe hardneſs and tenacity you are well acquainted, are expanded and rarified by heat in all their dimenſions: let us lay this rod of iron, which is ſix inches long, in the fire till it begins to grow red, and you will then find it to be about $\frac{1}{20}$th of an inch longer than it was before; that is, about 120th part of the whole. That the metal is proportionably expanded in breadth, you will ſee by trying to paſs it through this aperture, which it fitted exactly when cold, but which will not admit it now it is heated. This is one of the reaſons why clocks vary when carried into a hotter or colder climate; for the times of the vibrations of pendulums are always in the ſub-duplicate ratio of their lengths; and as the length is changed by heat and cold, the times of vibration will be alſo changed: the quantity of alteration, when conſidered in a ſingle vibration, is exceeding ſmall; but when the vibrations are often repeated, will be very ſenſible. An alteration of one hundred thouſandth part in the time of a ſingle vibration, will make a change of

of nearly one whole vibration in twenty-four hours.

Different metals lengthen differently with the ſame degree of heat: thoſe inſtruments, therefore, whoſe parts are to maintain a conſtant proportion, ſhould never be framed of different metals. It is from this unequal expanſion, that a harpſichord is deranged by a change in temperature.

To diſcover the minuteſt changes in expanſion, and the relative proportions thereof, an inſtrument has been conſtructed called a *pyrometer*.

Of Pyrometers.

Among the various machines that have been invented for this purpoſe, that contrived by Mr. Smeaton appears to be the moſt perfect: it's accuracy is confirmed by obſervations made with other inſtruments; it is founded on the following principles:

1. The quantity of expanſion being in proportion to the length of the bar, the longer the bar, the more ſenſible the expanſion.

2. The ſcale on which the alterations are meaſured, ought to be ſo large, as that the ſmalleſt alteration may be viſible.

3. The materials of which the meaſuring parts of the inſtrument are made, ſhould ſuffer no expanſion during the experiment, or the degree of expanſion produced in them ſhould be known and accounted for; becauſe the expanſion of the inſtrument, ſuppoſing the bar to be meaſured does not expand, will produce the ſame appearance as the expanſion of the bar, ſuppoſing the inſtrument not to expand.

4. All bodies continuing to expand, in proportion as the heat applied to them is increaſed, it is

is neceſſary to aſcertain the degree of heat applied, in order to determine the comparative expanſion of different metals. And,

5. The meaſuring parts of the inſtrument ought to be ſo large, as that the quantities of the meaſured expanſion may be known in real meaſure.

The inſtrument (*fig.* 1 and 2, *pl.* 5,) is ſo conſtructed as to receive a bar two feet four inches long, and might be made capable of receiving bars of a much greater length of ſome kinds of materials, but not of others, on account of their flexibility; even with a degree of heat not exceeding boiling water.

The meaſures are determined by the contact of a piece of metal with the point of a micrometer-ſcrew. *The obſervation is beſt judged of by the hearing, rather than that of the ſight or feeling:* by this method it has been found practicable to repeat the ſame meaſurement ſeveral times, without differing from itſelf above $\frac{1}{20,000}$th part of an inch. The degree of ſenſibility attained by this method is ſuperior to any thing that can be done by ſight or feeling.

As no ſubſtance has hitherto been diſcovered that is perfectly free from expanſion by heat, the bar which makes the baſis of the inſtrument ſuffers the ſame degree of heat as the bar to be meaſured; conſequently the meaſures taken by the micrometer are the differences of their expanſion.

The expanſion then of the baſis between two given degrees of heat being once found, the abſolute expanſion of any other body, by adding or ſubtracting the difference to or from the expanſion of the baſis, according as the body to be meaſured expands more or leſs than the baſis, will be determined.

When the inſtrument is made uſe of, it is immerged, together with the bar to be meaſured, in a ciſtern

ciſtern of water; which water, by means of lamps underneath, is made to receive an intended degree of heat, not exceeding that of boiling; and thereby communicates the ſame degree of heat to the inſtrument, to the bar, and to a mercurial thermometer immerged therein, for the purpoſe of aſcertaining the degree.

All that remained was to find the abſolute expanſion of the baſis between any two given degrees of heat, not greater than that of boiling water, which is thus effected.

For this purpoſe, let there be prepared a bar of ſtrait-grained white deal or cedar; which it is well known are much leſs expanſible by heat than any metal hitherto diſcovered: let the bar be adapted to the inſtrument, in like manner as the other bars intended to be meaſured; but that the ſoftneſs of the wood may not hinder the juſtneſs of it's bearings, let it's ends be guarded with a bit of braſs let into the wood at the points of contact, to prevent, as much as may be, the moiſture or ſteam of the water from affecting the wood: let it firſt be well varniſhed; and then, being wrapped round with coarſe flax from end to end, this will in a great meaſure imbibe the vapour before it arrives at the wood: let the ciſtern alſo be ſo contrived, that the inſtrument being ſupported at a proper height therein, the bar to be meaſured may, upon occaſion, be above the cover, while the baſis remains in the water; thus will the cover alſo be a defence againſt the moiſture. Let the water in the ciſtern be now brought to it's lower degree of heat, (ſuppoſe at or near the freezing point,) the baſis having continued long enough in the water to receive the ſame degree of heat; and the wooden bar having been previouſly kept in an adjacent room, not ſubject to ſudden alterations of temperature by fire, or other cauſes: let the bar be applied

applied to the inſtrument, and the degrees of the micrometer and the thermometer read off and ſet down: let the wooden bar be then reſtored to it's former place, till the water is heated to the greater degree intended (ſuppoſe at or near that of boiling water;) the lid being now ſhut down, and the chinks ſtopped with coarſe flax, to prevent the iſſuing of the ſteam as much as poſſible, let the wooden bar be again brought forth, applied to the inſtrument, and the degrees of the micrometer and thermometer read off as before: the difference of degrees of the micrometer correſponding to the difference of degrees of the thermometer, will expreſs the expanſion of the baſis between thoſe degrees of heat; that is, upon the ſuppoſition that the wooden bar was of the ſame length at the time of taking the ſecond meaſure, as at the firſt: indeed, a meaſure can hardly be taken without any loſs of time, as the whole of the inſtrument, when the hot meaſure is to be taken, is conſiderably hotter than the wooden bar; and, in caſe of boiling water, the ſteam being very repellent and active, the bar is liable to be ſenſibly affected in it's length, before the meaſure can be taken both by heat and moiſture, which both tend to expand the bar; but as the quantity is ſmall, and capable of being nearly aſcertained, a wooden bar thus applied, will anſwer the ſame end as if it was unalterable by heat or moiſture.

In order, therefore, to know the quantity of this alteration, let the time elapſed between the firſt approach of the bar to the inſtrument, and the taking of the meaſure, be obſerved by a ſecond-watch, or otherwiſe: after another equal interval of time, let a ſecond meaſure be taken; and after a third interval, a third and a fourth: the three differences of theſe four meaſures, will be found nearly to tally with three terms of a geo-

 metrical

metrical progreſſion, from which the preceding term may be known, and will be the correction; which, if applied to the meaſure firſt taken, reduces it to what it would have been, if the wooden bar had not expanded during the taking thereof.

From a few obſervations of this kind, carefully repeated, the expanſion of the baſis may be ſettled; and this once done, the making experiments upon other bars will become very eaſy and compendious.

The bar of braſs which compoſes the baſis is an inch broad by half an inch thick, and ſtands edgewiſe upwards: one end is continued of the ſame piece at right angles, to the height of three inches and an half, and makes a firm ſupport for the end of the bar to be experimented; and the other end acts upon the middle of a lever of the ſecond kind, whoſe fulcrum is in the baſis; therefore, the motion of the extremity of the lever is double the difference between the expanſion of the bar and the baſis. This upper part of the lever riſes above the lid of the ciſtern, ſo that it and the micrometer-ſcrew are at all times clear of the water: the top of the lever is furniſhed with an appendage called the *feeler*; it is the extremity of this piece which comes in contact with the micrometer-ſcrew. The conſtruction and application hereof will better appear from the draught than from many words: it hence appears that, having the length of the lever from it's fulcrum to the point of ſuſpenſion of the feeler, the diſtance between the fulcrum and the point of contact with the bar, the inches and parts that correſpond to a certain number of threads of the micrometer, and the number of diviſions in the circumference of the index-plate, the fraction of an inch expreſſed by one diviſion of the plate may be deduced; thoſe meaſures are as follow:

From

	Inches.
From the fulcrum of the lever to the feeler	5.875
From the fulcrum to the plate of contact	2.895
Length of 70 threads of the ſcrew -	2.455
Diviſions in the circumference of the index-plate - -	100

Hence the value of one diviſion will be the $\frac{10}{57863}$ part of an inch; but if the ſcrew be altered, one-fourth of one of theſe diviſions, when the contact between the ſcrew and feeler is well adjuſted, the difference of contact will be very perceivable to the ſlighteſt obſerver; and conſequently $\frac{1}{23145}$th part of an inch is perceivable in this inſtrument. There is one thing ſtill remains to be ſpoke of, and that is, the verification of the micrometer-ſcrew, which is the only part of this inſtrument that requires exactneſs in the execution; and how difficult theſe are to make perfectly good, is well known to every perſon of experience in theſe matters; that is, that the threads of the ſcrew may not only be equidiſtant in different places, but that the threads ſhall be equally inclined to the axis in every part of the circumference.

As nearly the ſame part of the ſcrew is made uſe of in theſe experiments, the latter circumſtance is what principally needs inquiry: for this purpoſe, let a thin ſlip of ſteel or other metal be prepared, whoſe thickneſs is about one-eighth of the diſtance of the threads: let the edges of this thin plate be cut into ſuch a ſhape as exactly to fit into the fixed notch, in which one end of the bar is laid: let a ſcrew paſs through the ſtandard of braſs on which that notch is ſupported, in ſuch a manner, that the end of the bar to be meaſured, that is fartheſt from the lever, may take it's bearing againſt the point (or rather the ſmall hemiſpherical end) of this ſcrew: let one of the braſs bars uſed in the other experiments be applied to the

instrument, and a measure taken; then let the thin plate be put in between the end of the bar, and the point of the screw last-mentioned, and again take the measure; but first observe that the plate is put down to the notch, so that the same place of the plate may always agree with the point of the screw; and consequently no error may arise from a different thickness in different places of the plate: observe also, that the whole comes to a true bearing; then advance the same screw till the micrometer-screw is pushed backward one-fourth of a revolution; again repeat the measure with and without the thin plate; again advance the former screw, so as to make that of the micrometer recede another quarter of a turn, and repeat the measures with and without the thin plate. This method being pursued as far as necessary, it is evident, that the thickness of the plate being always the same, if the difference of measures taken with and without it, are not always the same in the different parts of a revolution of the micrometer-screw, that this screw is not equiangular; but from the differences of the measures corresponding to the thickness of the same plates in the different parts of a revolution, the errors thereof may be nearly assigned. For greater certainty in this examination, lest the heat of the observer's body should affect the bar or instrument during the observation, let the whole be immerged in the cistern of water, which ought to stand a sufficient time before the observation is begun, to acquire the same temperature as the air, which also ought to be in a settled state.

Description of Mr. John Smeaton's New Pyrometer.

PLATE 5. fig. I. ABCD is the main bar or basis of the instrument.

EF is the bar to be measured, lying in two notches; one fixed to the upright standard AB; the other to the principal lever HI. The end E of the bar EF bears against the point of

G, a screw, of use in examining the micrometer-screw.

The other end of the bar F bears against a small spherically protuberant bit of hard metal, fixed at the same height as G, in the principal lever HI.

K is an arbor fixed in the basis which receives at each end the points of the screws H, L, upon which the lever HL turns, and serves as a fulcrum thereto.

O is a slender spring to keep the lever in a bearing state against the bar; and

P is a check, to prevent the lever from falling forward, when the bar is taken out.

N is the feeler, something in the shape of a T suspended, and moveable up and down upon the points of the screws I, M, which, as well as L, H, are so well adjusted as to leave the motion free, but without shaking.

R is the handle of the feeler, moveable upon a loose joint at R; so that laying hold of the knob, the feeler is moved up and down, without being affected by the irregular pressure of the hand.

The extremity, S, of the feeler, is also furnished with a bit of protuberant hard metal, to render it's contact with the point of the micrometer-screw the more perfect.

T is the micrometer-ſcrew.

V is the divided index-plate; and

W is a knob for the handle.

The micrometer-ſcrew paſſes through two ſolid ſcrewed holes at D and Y.

The piece YZ is made a little ſpringy, and endeavours to pull the ſcrew backwards from the hole at D; and of conſequence keeps the micrometer-ſcrew conſtantly bearing againſt it's threads the ſame way, and thereby renders the motion thereof perfectly ſteady and gentle.

X is the index, having diviſions upon it, anſwering to the turns of the ſcrew. This piece points out the diviſions of the plate, as the face of the plate points out the diviſions upon the index.

When the inſtrument is uſed, lay hold of the knob of the feeler with one hand, and, moving the feeler up and down, with the other move forward the ſcrew T, till it's point come in contact with the feeler; then with the plate and index, V and X, ſhew the turns and parts.

Fig. II. repreſents the inſtrument immerged in a ciſtern of water, ready for uſe.

AB is the ciſtern, C the cover, which, when the inſtrument is raiſed upon blocks, goes on between the bar EF, and the baſis BC, fig. I.

D is a handle to take off the cover when hot.

E a mercurial thermometer, whoſe ball is in the water.

F a cock to let out the water.

GH is a hollow piece of tin, which ſupports ſeven ſpirit lamps, which are raiſed higher, or let down lower, by the ſcrews I and K, in order to give the water a proper degree of heat, ſhewn by the thermometer E.

A Table

A TABLE *of the* EXPANSION *of* METALS.

Shewing how much a foot in length of each grows longer by an increase of heat corresponding to 180 degrees of Fahrenheit's *thermometer, or to the difference between freezing and boiling water, expressed in such parts whereof the unit is equal to the 10,000th part of an inch.*

1. White glass barometer tube -	100
2. Martial regulus of antimony -	130
3. Blistord steel - -	138
4. Hard steel - - -	147
5. Iron - - -	151
6. Bismuth - - -	167
7. Copper hammered - -	204
8. Copper, 8 parts mixed with one of tin	218
9. Cast brass - - -	225
10. Brass, 16 parts, with tin 1 -	229
11. Brass wire - - -	232
12. Speculum metal - -	232
13. Spelter solder, *viz.* lead 2 parts, zinc 1	247
14. Fine pewter - -	274
15. Grain tin - - -	298
16. Soft solder, *viz.* lead 2 parts, tin 1	301
17. Zinc 8 parts, with tin 1, a little hammered	323
18. Lead - - -	344
19. Zinc, or spelter - -	353
20. Zinc, hammered half an inch per foot	373

OF THE POWER EXERTED BY FIRE IN EXPANDING METALS, &c.

If you consider for a moment the vast weight which may be suspended from a bar of brass or iron, in a vertical position, without separating the parts of the metal; that is, without overcoming the force with which they adhere together; you may form some idea of the great force of fire, which

which can ſo far relax the texture of iron and braſs, that their parts will *fall aſunder* with the force of gravity alone. To render this force evident, the Rev. Mr. Jones contrived this inſtrument (*fig.* 3, *pl.* 5,) which is a compound ſteel-yard; where, by means of a ſlender rod of deal, the ſpace deſcribed by the third lever is augmented, and made more perceptible: the motion of the ſhort arm is to the motion of, or ſpace deſcribed by, the long arm, as 1 to 100; ſo that five pounds at the end of the long arm will compreſs the bar at the end of the ſhort one, with a force equal to a weight of 500*lb.* I ſhall put on a weight of 5*lb.* at the end of the long arm, and apply the flame of this farthing candle to the bar acting on the end of the ſhorter arm: you ſee plainly, by the motion of the index, that the expanding power of fire in this ſmall compaſs is equal to 500*lb.* and there is no doubt but that the flame of this candle would overcome a weight of 5000*lb.* with the ſame eaſe, if the parts of the inſtrument would bear the ſtreſs neceſſary for ſuch a trial.

Fluids are expanded by fire as well as ſolids; thoſe employed in thermometers furniſh us with a ſufficient proof of this, as heat can only raiſe the fluid contained, by expanding and dilating the volume thereof. I ſhall explain the nature of thermometers in our next Lecture. Fluids expand more or leſs, ſooner or later, according to their nature.

To give you an ocular demonſtration of this expanſive power, take this glaſs globe, with a long glaſs neck annexed to it; fill it with water up to the firſt mark on the neck; then immerge it into a veſſel of hot water: you ſee the water mounts up into the neck, and will continue riſing as the heat of the water increaſes; or if you take it out of the water, and apply it nearer and nearer to the

fire,

fire, you will find it dilate more and more, in proportion as you approach; but upon removing it from the fire the water ſinks again: a clear proof that fire dilates it ſo as to make it occupy more ſpace when hot than when cold.

It appears that fluids of the leaſt denſity expand moſt with the ſame degree of heat: thus inflammable air dilates more with the ſame heat than common air, common air more than ſpirits of wine, ſpirit of wine more than linſeed-oil, linſeed-oil more than water, and water more than mercury. But if you conſider the time neceſſary for each fluid to acquire the greateſt degree of rarifaction it is ſuſceptible of, there is no known law to guide us. Mercury, though much more denſe than water, requires leſs time; while water employs more time than ſpirit of wine, which is leſs denſe; yet water, which is more denſe than linſeed-oil, requires leſs time to attain it's greateſt degree of rarifaction. Theſe variations depend on cauſes which have not yet been unfolded. Meſſrs. Bucquet and Lavoiſier have made a long courſe of experiments on the dilatation of fluids by heat, and it's progreſs, without diſcovering the cauſes of the ſingular diverſity they obſerved; and have, therefore, contented themſelves with deſcribing the facts, without drawing any inferences.

ON COHESION.

It will be worth while in this place to conſider the opinions of a modern philoſopher on coheſion; they are founded on an experimental inveſtigation of the ſubject; and open a field, that, if properly purſued, will throw great light on every phenomenon of nature; they are indeed in direct oppoſition to a feigned attraction of coheſion. The experiments that have been uſually adduced in ſupport of this attraction, muſt now be

be given up, as having no concern with the principle in question; but belonging to the class of hydrostatical phenomena, not to that of immaterial qualities exerted by the particles of bodies themselves.*

It is difficult to say how the attraction of cohesion came to be assumed as a principle by those who contended for experiment, as the basis of philosophy. That there are powers by which cohesion is produced, no one will deny; but cohesion is not a principle sufficiently generalized, to be admitted into philosophy; as a cause of which we may calculate the effects: nor is it understood in that perfect manner which a principle requires.

General observation and matter of fact may always be opposed to a thousand little critical experiments. You observe that nature is provided with the element of *fire;* a material agent, of sufficient force and subtilty to overcome and undo the strongest effects ascribed to cohesion: and as you also know that the design of the CREATOR was to build rather than to destroy, more to promote an orderly disposition of bodies, than to cause their dissolution, you will be led to suppose that the same agent acting with some difference of condition and circumstances, is able to affect both the one and the other.

The *air*, for instance, when stirred into a tempest, will tear an oak up by the roots; but does not the same air assist the oak and all other trees in their growth? Does it not nourish and preserve many more than it destroys? Fire hath, in like manner, it's different offices: that it is the great catholic dissolvent of nature, few will deny; and that it can unite as well as separate, ought not to be doubted.

Let

* Jones's Physiological Disquisitions.

Let us consider it for a moment as a dissolvent: the particles of mercury, from their sphericity, seem endued with a strong attraction; yet these will cease to have any cohesion, and be separated into vapour by a degree of heat but little exceeding that of boiling water. The agency of fire, in the same manner, soon relaxes the cohesion of water; a greater degree dissolves the union of it's particles, and raises them aloft in steam or vapour. All other substances, solid and fluid, are subject to a separation of their parts by the entrance of fire: the hardest metals, how closely soever their parts may be connected, are easily dissolved, and rendered fluid by the heat of a furnace. If nature be provided, by it's *Author*, with an element of such power and activity, as enables it to *overcome* the strongest cohesions, it cannot be destitute of an agent powerful enough to cause them: if it can do the greater, it can certainly do the less. Fire acting below a certain degree, consolidates water into ice; if it acts above that degree it keeps it fluid; if to a higher degree, a total separation of parts ensue, the effects being answerable in every instance to the activity and condition of a *material* agent. Two pieces of metal can never be joined so as to possess their peculiar metallic tenacity, but by the agency of fire. When you thus see the effects vary, as often as there is any change in the element of fire, you are compelled by all the rules of *reason* and *philosophy*, to understand this element as the immediate *cause* of those effects, and must receive it as such, till it is demonstrated to be inadequate.

The cohesion of bodies by the action of this fluid, may be illustrated and confirmed by some parallel effects: here is a stop-cock fastened to the neck of a bladder, that it may be screwed on the plate of our air-pump; we will do this, and exhaust

haust the air from it: this done, turn the ſtop-cock to prevent the air from re-entering; take it off the pump, and the bladder is, as you ſaw before in one of the preceding Lectures, transformed into two flat ſkins, ſo ſtrongly applied together, that you cannot, with all your force, ſeparate one from the other: on the contrary, if you fill the bladder with air, and turn the ſtop-cock, to prevent it from getting out, you will find it more difficult to bring the ſides together (if the bladder be not ruptured in the attempt,) than it was before to ſeparate them. Now, ſuppoſing a perſon preſented with this ſpectacle, unacquainted with the preſſure of the atmoſphere, as you were before this courſe of Lectures, what would he have ſaid, when, pulling at the ſides of the bladder, he found it impoſſible to lift up either of them. If acquainted with philoſophical terms, he might ſay, that nature abhors a vacuum; or he might conſider it as an undeniable proof of *attraction*. When the bladder is blown up, ſuppoſing him ſtill ignorant of the fluid within it, he would probably ſay that the ſides *repel* each other, or that they are *elaſtic*; attributing that elaſticity to the ſolid matter of the membrane, which is the property of the ſolid medium within it. You remember our experiments with the *Magdeburgh hemiſpheres*: you know that if the air be exhauſted from within, there will be an exceſs of preſſure without, which fixes the hemiſpheres firmly together; admit the air, and they fall aſunder. As every fluid is naturally in *equilibrio* with itſelf, the air, when applied to both the inner and outer ſurfaces, will preſs with equal and contrary forces, which of courſe, by counteracting, deſtroy each other.

As the entrance of the air deſtroys the adheſion, by reſtoring the equilibrium, it is plain there was not an equilibrium before; the action from

from within muſt have been weaker than the action from without: when the former of theſe is made equal to the latter, the coheſion ceaſes; it is *one and the ſame fluid* that on this occaſion exerciſes the offices of *uniting* and *ſeparating* the hemiſpheres.

Let us now paſs from the ſurfaces of the braſs hemiſpheres, to the coheſion of braſs: this, when thrown into the furnace, ſoon grows red; and as the heat increaſes becomes in a manner tranſparent: the matter of fire penetrates into the body of the metal, and when the medium within is nearly in the ſame condition as the medium without, there is an end of it's coheſion.

An effect which is thus made to ceaſe in a mechanical way, may be produced in the ſame way; and if the entrance and extrication of the fire diſſolves and ſeparates the parts of the metal, why may not the preſſure of the ſame element be the true cauſe of their coheſion; the fire within combining itſelf at the ſame time with the particles of the metal, ſo as to have leſs power to exert itſelf againſt this external preſſure. If you deny the preſſure of the air, you muſt have recourſe to attraction or ſuction, or an incorporeal agency, to account for the adheſion of the hemiſpheres. Allow but the exiſtence and preſſure of elementary fire, the reality of which is manifeſted to as many of the bodily ſenſes as air, and you need not have recourſe to any of theſe things to account for the coheſion of the braſs. If any experimentaliſt can exhibit one ſingle ſolitary inſtance of a cohering body, where he can prove the internal and external preſſures to be equal in all reſpects, we will grant him in this caſe his attraction, and confeſs that this effect is not brought to paſs in a *phyſical* way; and that we underſtand no more of the cauſe of it's

co-

cohesion than he has expressed under that *word*; which is just nothing at all.

The effects of heat and cold, as daily exhibited to our senses in the ordinary changes of the weather, are sufficient to justify the foregoing inferences. When the weather grows warm, the power of cohesion grows weaker: when the weather becomes cold, this power is increased; and the hardest of metals, in common with all other bodies, are proportionably altered in their dimensions. Extreme heat will dissolve them; extreme cold will harden and render them so brittle, that large bars of iron may be easily snapt asunder, after they have been exposed all night in the open air, to a severe frost. A power of so fluctuating a nature, and which is thus increased and diminished with every change of the elements, can be no property of the cohering matter. If the changes of the atmosphere are found to make the heights of the barometer vary, who can doubt that *the pressure of the air* is the sole and adequate cause of it's suspension? And accordingly, if the air be totally removed from the surface of the cistern, the mercury drops to a level with it: thus also, if the degrees of density in a cohering body, vary with the degrees of heat, where should we seek but in the *element of fire* for the true and physical cause of cohesion.

Every thing points out that cohesion corresponds with what we conceive to be acting, when a body is diminished in volume by losing it's power of dilatation: it is a power that is always overcome as to this effect, when the opposite power, or that of dilatation, is increased.

The operation of fire is varied according to the several conditions in which it may be found to act. In resisting the action of that gravitating matter

matter by which the parts of the body tend to approach, the operation of the matter opposed is called heat, and distinguished in being that of dilatation; therefore, when the volume in certain cases is augmented, the heat of dilatation is the proper power by which this change is effected: but, when the volume of a body is, on the contrary, diminished by the influence of another body, that is cold, then the proper action of heat in the condensed body, is as much overcome as is that of gravitation in the other, which is then dilated.

Natural bodies may, therefore, be considered as influenced by an agent acting in two different modes: in the one, diminishing the volume of the body; in the other, augmenting this volume in dilatation. The limited extension of the body is thus conceived, as consisting in the proper ballance of those opposing agents.

Hence, as the fixed volume of a body (which is not absolute or real, but apparent,) arises from the ballance of it's powers; so the actual and perceived changes in the volume of a body, are occasioned by the prevalence of one or other of those powers, according as increase or diminution of volume is the effect; and thus in the one case it is the dilating power of fire which is manifested; in the other it is the compressing action of gravitation that is to be considered as the immediate cause; though the more remote one is the abstraction of fire (or that cessation of it's action as heat,) which, in common language, is the operation of cold.

Fire, when acting as heat, is a power acting in the opposite direction to that principle of gravitation, by which the union of matter is effected: these, therefore, are the principles by which the volumes of bodies are determined, and consequently preserved.

These

These also give rise to the power by which elasticity is produced. An external force endeavouring to compress a body into a smaller volume, conspires with the proper action of gravitation, and opposes that of heat: if, therefore, after having diminished the volume of the body by compression, the external force is removed, as the proper powers of the body remain, *elasticity* should appear, by which the natural volume of the body is restored.

OF TRUE AND FALSE PHILOSOPHY.

Of the various distinctions which characterize philosophy, there are none which deserve so much your attention as those which separate what is true from what is false: from these you will learn, that those men who assume the name of philosophers, to countenance infidelity and licentiousness, are not less enemies to philosophy than to divinity.

The mind of *that man* who conceives so falsely of the Divine oracles, as to believe that they oppose true and useful learning, has been debauched by sophistical reasonings, or debased by groveling and unworthy pursuits. Sacred writ arms us, indeed, against *vain* philosophy, and all the empty fictions of the human imagination, which bring forth neither pleasure nor profit; but then it invites you, in the sublimest strains, to consider the works of God, whose counsels and perfections, as they are displayed in the *creatures*, will ever be best understood by those who study *them* with humility and attention.

Learning and philosophy never shone more bright than when they met with faith and religion in the mind of the excellent Lord *Bacon;* whose opinion it was, that the wonderful works of God *do minister a singular help and preservation against infidelity*

infidelity and error. If there be any philoſophers ſo void of underſtanding, as to regard the ſcience of nature, only as a tower of ſtate for a proud mind to raiſe itſelf upon; and to eſteem themſelves licentiates in infidelity, becauſe they make ſome figure in philoſophy; it may poſſibly do them ſome good, to look back upon the example of this great man, who preſerved a mind untainted with the pride of hereſy and infidelity; and was not more to be admired for his extenſive learning and experience in the ways of nature, than for his theological ſkill and penetration into the wiſdom of the ſacred writings: "*There are,*" ſays he, "*two books, or volumes of ſtudy laid before us: if we will be ſecured from error, firſt, the Scriptures revealing the will of God, and then the creature's expreſſing his power, whereof the latter is a key unto the former: they are both written by the finger of the one eternal God.*"

In theſe we are taught that the ſame God, who created the world in wiſdom, *upholds* it in mercy; that in him we live, and move, and have our being. If the ſun gives us light and warmth, it is *his ſun,* which he maketh to riſe on the evil and the good. If the clouds pour down their water upon our fields, to nouriſh and bring forward the fruits of the earth, it is he that *ſendeth rain* on the juſt and unjuſt: to him, therefore, the bleſſings that are diſpenſed to us in the ordinary courſe of nature, are to be devoutly aſcribed, as to the primary ſource of all life and motion. This concluſion will be equally true, whether God is ſuppoſed to diſtribute the benefits of nature from his own hand immediately, or by the mediation of ſecondary cauſes of his own appointing; for either way the real government of the whole can only terminate in himſelf.

There are ſome who diſpute againſt the operation of ſecond cauſes,* as thinking it to derogate from the power of God, that he ſhould ſtand in need of their aſſiſtance. But they ſhould be told, that God did not make the world becauſe he himſelf ſtood in need of any thing: it was for the benefit of his creatures; and with the ſame views he eſtabliſhed the operation of ſecond cauſes, conſulting therein *our* wants, not his own.

Man is a compound being, made up of two different parts that claim a kindred with two different worlds, the viſible and inviſible. The natural, or bodily part, muſt be ſupported by natural powers; the ſuperior, or ſpiritual part, by God, who is a ſpirit, and whoſe powers alone can poſſibly extend to it's wants. When nature ſhall ſink, and the ſpiritual world open upon us, God himſelf will take the place of all inferior cauſes. A ſpiritual interpoſition is not wanting in the *Chriſtian* diſpenſation; but then it is calculated for the benefit of man's *ſpirit*, while his body is left to the ways of nature. The two kingdoms of nature and grace, as two parallel lines, correſpond to each other, follow a like courſe, but can never be made to touch. An adequate underſtanding of this diſtinction in all it's branches, would be the conſummation of human knowledge.

* "Certain it is," ſays Lord Bacon, "that God worketh nothing in nature, but by ſecond cauſes; and if they would have it otherwiſe believed, it is mere impoſture, as it were in favour towards God, and nothing elſe but to offer to the Author of Truth the unclean ſacrifice of a lie."

LECTURE

LECTURE VII.

On Fire.

HEAT and cold are perceptions of which we acquire the ideas from the ſenſes: properly ſpeaking, theſe ideas only indicate a certain ſtate in which we find ourſelves independent of any exterior object.

But as theſe ſenſations are, for the moſt part, produced by ſome of the bodies which ſurround us; and as they are generally accompanied in the bodies themſelves by an augmentation or diminution of fire, we conſider them as cauſes; and, judging by appearances, we apply the names hot and cold to the ſubſtances themſelves, calling thoſe hot, which produce in us the ſenſation of heat, and thoſe cold, which communicate the ſenſation of cold. Whatever be the nature of that quality in bodies which we call heat, we are aſſured it does not reſemble the ſenſation of heat: it is no leſs abſurd to ſuppoſe a likeneſs between the ſenſation and the quality, than it would be to ſuppoſe that the pain of the gout reſembles a ſquare or a triangle. The moſt unlearned man, if endued with common ſenſe, never imagines the ſenſation of heat, or any thing that reſembles it, to be in the fire; he only imagines that there is ſomething in the fire which occaſions this ſenſation: but as the name more frequently ſignifies this unknown ſomething, than the ſenſation occaſioned by it, he juſtly laughs at the philoſopher who denies that there is any heat in the fire. The contradiction, however, between the philoſopher and the vulgar, is more apparent than real, and is owing to an abuſe of language on the part of the philoſopher, and of

indiſtinct notions on the part of the vulgar. The philoſopher ſays there is no heat in fire, meaning that the fire has not the ſenſation of heat: his meaning is juſt, but his language is improper; for there is really a quality in fire, of which the proper name is heat; a name given to it more frequently both by the philoſopher and the vulgar, than to the ſenſation of heat: and when he explains himſelf, and ſays that fire does not feel heat, the difficulty vaniſhes, and the vulgar will agree with him.*

And further, heat and cold ſignify as well our ſenſations, as the modifications of bodies occaſioning them: therefore, though we ſay the fire is hot, and makes us hot, we do not mean the ſame thing by the ſame word in both places: thus when we talk of fire melting metals, or burning combuſtibles by the intenſeneſs of it's heat, we mean the property it has of producing the alterations we ſee made in thoſe bodies; and this we denominate heat, from that beſt known effect we find it have upon ourſelves, in raiſing a burning ſmart in our fleſh whenever we approach near enough; therefore, thoſe who would find fault with us for attributing heat, &c. to inanimate bodies, are too haſty; for by ſuch expreſſions we do not underſtand the ſenſations, but the qualities giving riſe to them, which qualities really belong to the bodies: ſo that with your plain neighbours you may maintain ſnow to be white, fire hot, ice cold, roſes ſweet, poppies ſtinking, wormwood bitter, and the like; and this you may juſtly do without offence to propriety of ſpeech, or to ſound philoſophy.

Our ſenſations depend not only on the ſubſtances which excite them, but on the actual ſtate of

* Reid on the Intellectual Powers of the Mind.

of our bodies at that time; we cannot, therefore, conclude the exact identity or similarity of the cause from the sameness of the sensations, unless we could be assured our bodies were in the same state; if they be not, the same object will produce very different sensations: thus, if you plunge your hand into luke-warm water, the water will appear cold, if your hand be warm; but if your hand be cold, the water will appear to be warm, though in both cases it possesses the same temperature.

OF SENSIBLE HEAT.

Heat and cold are not names of things essentially different, but only of different degrees of the same thing; that is, of fire in motion. The penetrating power of fire considered as a sensation, or, in other words, *sensible heat*, is only the effect produced upon our sentient organs, by the motion or passage of fire disengaged from the surrounding bodies. When you touch a cold body, fire, which always tends to an equilibrium in all bodies, passes from your hand into the body you touch; this loss of fire communicates to us the sensation of cold. The contrary happens when we touch a warm body; the fire then passing from the body into our hand, produces the sensation of heat; if the hand and the body touched be of the same temperature, or very nearly so, we receive no impression of heat or cold: our sensations are, therefore, both imperfect and deceitful measures of heat, and will not ascertain the condition of bodies, with respect to heat and cold; hence philosophers have sought for some method by which they determine the temperature of bodies with certainty: this they found in that property of heat, whereby it expands and dilates all bodies, which are consequently contracted by less degrees of heat, or what we term cold.

OF THERMOMETERS.

The thermometer (*fig.* 4, *pl.* 5,) is the instrument devised by science, and executed by art, as the most extensive and accurate means of information, with respect to the diffusion of heat among bodies. It is perceptibly affected by the dilatation of a small quantity of fire received, or by the condensation following upon the separation of a similar quantity of fire: consequently, when this instrument is severally connected with bodies being in a separate state, the different or equal temperatures of those bodies may be discovered by the thermometer, according as it shall either indicate diffusion, or no diffusion, of heat on these occasions. In other words,

Thermometers are instruments to measure the degree of heat by the expansion and contraction of different substances. *Fluids* are those generally used, because they dilate more readily than solids. *Quicksilver* is preferred to other fluids, 1. From it's unchangeableness: 2. For the regularity of it's expansion: 3. Because it does not soil the tube.

A mercurial thermometer consists, as you see, of a tube of glass, the end of which is blown into a ball or cylinder; the ball, and part of the tube, is filled with mercury: the expansion or contraction of the mercury is shewn by the rise and fall of the mercury in the tube, which is measured by the scale affixed thereto. The smaller the bore or diameter of the tube is, the more visible will be the rise of the fluid by a small expansion. It is not sufficient, however, to have found a measure of heat; it must also be universal; that is, speak the same language, and raise the same ideas in the mind in all places, and at all times. To this end it is necessary, 1. That this measure should begin from a known and determinate point: 2. That another

other point be aſcertained at ſome diſtance from the former, but equally fixed and certain: 3. That the ſpace between theſe two points be divided into a given number of degrees, ſo that the ſcale may always have a conſtant and known proportion.

It has been clearly proved, by numerous experiments, that the freezing-point of water, or temperature of ice or ſnow at the inſtant of formation, or rather when it is beginning to liquify, is conſtantly the ſame in all places, and at all times. The ſame may be ſaid of the boiling-point of water, or the temperature at which, under a given preſſure of the atmoſphere, an ebullition takes place. If, therefore, the bulb of a thermometer be plunged into melting ſnow, and afterwards into boiling water, and be kept in each till it acquires their temperature, and marks are made at the reſpective heights the mercury ſtands at on the immerſion in each temperature, two fixed points will be obtained. To make this plainer, if you put the bulb of a mercurial thermometer into melting ſnow, it will fall to a certain point, where it will remain till the ſnow be melted; ſhewing you that ſnow has always a certain degree of coldneſs, and has the power of reducing mercury to the ſame degree. In the ſame manner, if you plunge your thermometer into boiling water, it always riſes to the ſame height. While you are in health, if you place the bulb of a thermometer in the mouth, it will always riſe to a certain point.

In a good thermometer it is neceſſary that the ſpace between the mercury and the ſealed end of the tube be free from air; if this be effected, the mercury in the tube will run backwards and forwards upon inverting the inſtrument. The ſcale muſt be adjuſted to the inequalities of the tube; the fixed points muſt be accurately aſcertained.

The thermometers moſt in uſe at preſent are *Fahrenheit*'s, *Reaumur*'s, and *Celſius*'s. In Fahrenheit's ſcale, the number of degrees between the freezing and boiling water point is 180; the freezing point being at 32°, and the boiling point at 212°: both the numbers are above 0, or the point from which the degrees are numbered both ways. In Reaumur's ſcale the number of degrees between theſe two points is 80, and the freezing point is called 0°. In Celſius's thermometer the interval is divided into 100, and the freezing point is 0°, as in Reaumur's. To reduce theſe ſcales to each other, you muſt obſerve that one degree of Fahrenheit's is equal to four-ninths of a degree of Reaumur's, and to five-ninths of a degree of Celſius's: therefore, if you multiply the number of degrees below or above the freezing point of Fahrenheit's by 4, and divide the product by 9, the quotient will be the correſponding number on Reaumur's ſcale. If the multiplier 5, and the diviſor 9, be uſed, the quotient will give the degrees of Celſius's ſcale: and, on the contrary, if any number of degrees be multiplied by 9, and divided by 4, if of Reaumur; by 5, if of Celſius; the quotient will give the degrees of Fahrenheit, either above or below the freezing point, according to the caſe.

The dilatations and contractions of the mercurial thermometer are nearly proportional to the quantity of fire, which are communicated to the ſame homogeneous bodies, or ſeparated from them, as long as they retain the ſame form: thus the quantity of heat required to raiſe a body, four degrees in temperature by the thermometer, is nearly double that which is required to raiſe it two degrees; four times that required to raiſe it one degree, and ſo in proportion.

The

The determination of the correſpondence between the degrees of the thermometer, and the actual variations of the heat of fluids, has been accurately inveſtigated by Mr. De Luc: he laid it down as a principle, *That if equal quantities of hot and cold water be mixed together, the difference of heat will be equally divided between them:* from whence it was concluded, that a thermometer being immerſed in hot water, and alſo in cold, previouſly to the mixture, if the expanſions were in proportion to the quantities of fire communicated, it would point after the mixture to the arithmetical mean, or to half the difference of the ſeparate heats added to the leſs, or ſubtracted from the greater. Thus, a quantity of water at 45.5,* being mixed with an equal quantity at 200.75, the thermometer indicated ſomewhat leſs than the arithmetical mean; the deviation was not more than two degrees below that point. The experiment was repeated at different temperatures with a ſimilar reſult; from whence M. De Luc inferred that the mercurial thermometer is nearly an accurate meaſure of heat. The experiments from which this fundamental principle is derived, have been examined with peculiar care and accuracy by Dr. Crawford; who ſtill found that the expanſions of the mercury in the thermometer, are correſpondent with the heat it receives; and that it is, therefore, an accurate meaſure of heat.

When the thermometer is riſing, it ſhews that fire is entering into the ſurrounding bodies: the thermometer, which is one of theſe, receives it's ſhare in proportion to it's maſs, and the capacity it has for containing fire. The change, therefore, which takes place in the thermometer, announces

* We always mean Fahrenheit's ſcale, unleſs when otherwiſe noticed.

nounces a ſtate of action, and probably a change of place in the fire contained in the ſurrounding bodies, and of which itſelf forms one part: it indicates the portion received; but is not a meaſure of the whole quantity diſengaged, diſplaced, or abſorbed. We cannot deduce with accuracy from it the fire which eſcapes from living bodies, or determine with preciſion the temperature of any ſubſtance; for the ſcale of the thermometer is a ſcale of *expanſion*, not of heat.

As it is eſſential to conceive clearly what is really indicated by the thermometer, let us ſuppoſe a thermometer in a veſſel full of water: now both the water and the thermometer contain fire, and this has a tendency to quit both. If this force be equal in each, the mercury will neither riſe nor fall on plunging the inſtrument into the water, becauſe fire has the ſame degree of expanſibility in each; and the thermometer ſhews, by the degree on it's ſcale, the *temperature* of the fluid.

If the expanſive force of the fire in the water, or it's tendency to quit the water, be greater than that of the fire in the thermometer, it will paſs into the thermometer, and expand the mercury till the fire in each has the ſame force; ſo that the mercury will in this caſe alſo indicate the temperature of the fluid. If the tenſion of the fire be leſs in the water than in the thermometer, the exceſs will be communicated by the thermometer to the water until they have acquired an equilibrium; the thermometer will deſcend as the fire abandons it, and ceaſe to deſcend when the expanſive force is equal in each; ſo that in this caſe alſo it indicates the temperature of the water. *

But this expanſive action of fire depends on two

* See Pictet on Fire.

two caufes: the degree of it's accumulation, or abfolute denfity, and on the faculty of the fubftance in which it is accumulated, to reftrain or retain it, which is often called it's *fpecific heat*: the expanfibility is in the direct ratio of the denfity, and inverfe of the fpecific heat. From what has been faid, I hope it ftill appears more evident, that *thermometers* do not teach us any thing concerning the abfolute, or even relative quantity of fire that is contained in bodies: *They only indicate the tranflations or transfufions of the igneous fluid; and fubdivide into nearly equal aliquots, a certain portion of the entire fcale of heat.*

OF LATENT FIRE, AND SPECIFIC HEAT.

Let us fuppofe a point, or focus, from whence there iffues a conftant and uniform emanation of fire; and that at equal diftances round it feveral fubftances of the fame nature and fize be placed; thefe will all be penetrated by the igneous emanation, and their temperature will rife by equal degrees, and will ceafe to rife when the fire within fhall have acquired an expanfive force equal to that of the emaning fire: but if the fubftances, though of equal mafs or weight, are of a different nature; as, for inftance, a pound of water, a pound of glafs, a pound of mercury, &c. the fire will penetrate them all, and they will all finally acquire the fame temperature, but in different fpaces of time, and by diffimilar degrees. This may depend on two caufes not eafily feparable: the different permeability of thefe fubftances to the matter of fire, or to their faculty of conducting heat, in virtue of which a longer or fhorter time is required to penetrate their texture. The greater their faculty of containing or retaining liberated heat, the more will they permit the accumulation thereof, before an equilibrium in the expanfive force takes place;

place; consequently you cannot infer that this equilibrium is occasioned by equal accumulations of fire.

If an hygrometer be applied to different substances, as blotting paper, spunge, and wood, the moment they are taken out of the water, it might shew us that they were equally wet, but would leave us altogether ignorant of the quantities of water they contained: in like manner, the thermometer applied to substances heated to the same degree, will shew that the fire has an equal expansibility in each; but it teaches us nothing as to the absolute or relative quantities of fire which produce this tendency: but you may obtain the relative quantities of water in the three substances, by drying them to the same degree in an apparatus proper to select separately the water which will abandon them. So you may likewise obtain the relative quantities of fire contained by the various substances heated to the same thermometric degree, if you cool them to the same degree in an apparatus proper to receive and measure separately the quantity of fire which abandons them during their refrigeration: this may be effected either by means of mixture, or by the apparatus contrived by Messrs. Lavoisier and De La Place. This reasoning, as well as the experiments on which it is founded, are clear proofs of the materiality of fire.

Fire, considered in this point of view, as accumulating in a greater or less quantity in substances of different natures, but of equal masses, and in which it acquires the same expansive force, is often termed *specific heat:* it is the relation of the quantities of fire necessary to raise different substances of equal masses to the same temperature.

To

To discover the quantity of fire contained in bodies, Meſſrs. Lavoiſier and De La Place invented a ſimple, but admirable inſtrument, to which they have given the name of *calorimeter*, or apparatus for meaſuring the relative quantities of fire contained in bodies; it is founded upon the following principles, 1. That if any body be cooled to the freezing point, and then expoſed to an atmoſphere of 88.25, it will be heated gradually from the ſurface inwards, till at laſt it acquires the ſame temperature with the ſurrounding air; 2. That if a piece of ice be placed in the ſame ſituation, the circumſtances are quite different; it does not approach in the ſmalleſt degree towards the temperature of the circumambient air, but remains conſtantly at 32° (or the temperature of melting ice) till the laſt portion of ice be completely melted: in other words, *That ice abſorbs all the fire communicated to it, without communicating it to other bodies, until the whole be melted;* and conſequently that we may calculate the degrees of heat communicated by the quantity of ice which is melted.

This phenomenon is thus explained: To melt ice, or reduce it into water, it muſt be combined with a certain portion of fire: the whole quantity firſt communicated, is fixed at the ſurface of the external layer of ice; this it diſſolves, combining with it to form water; the next quantity combines with the ſecond layer, and forms it into water; and ſo on ſucceſſively, till the whole ice is diſſolved and converted into water by being combined with fire; the laſt atom ſtill remaining at it's former temperature, becauſe the fire never penetrates ſo far, as long as any intermediate ice remains to be melted.

Upon theſe principles, if you imagine a hollow ſphere of ice at 32°, placed in an atmoſphere of 54 5°, and containing a ſubſtance at any degree

gree of temperature above freezing, it will follow, 1. That the heat of the external atmoſphere cannot penetrate into the internal cavity of the ſphere of ice: 2. That the heat of the ſubſtance placed, cannot penetrate outwards beyond it, but will be ſtopped at the internal ſurface, and continually employed in melting ſucceſſive layers of ice, until it's temperature is reduced to 32°, by having all the heat above that temperature carried off by the ice: 3. If the quantity of water within the ſphere of ice during the experiment be carefully collected, the weight of the water will be exactly proportional to the quantity of fire loſt by the body in paſſing from it's original temperature to that of melting ice; it being evident that a double quantity of fire would have melted a double quantity of ice; and that the quantity of ice melted is an exact meaſure of the quantity of fire employed to produce the effect; and of the quantity loſt by the only ſubſtance from which it could be obtained. The foregoing ſuppoſition is only made to explain more readily the nature of the experiments and apparatus uſed by M. De La Place: an apparatus ſo contrived, 1. That the ice abſorbs all the fire diſengaged from the bodies under examination: 2. That the ice is ſecured from the action of every other ſubſtance which might facilitate it's fuſion: and, 3dly, To collect with care the water produced by the fuſion.

The apparatus conſiſts, as you ſee, of three circular veſſels, nearly inſcribed in each other, (*fig.* 12 and 13, *pl.* 4,) ſo that three vacancies are produced. The interior ſpace or vacancy is formed by an iron grating upon ſupports of the ſame metal; here it is that the bodies ſubjected to experiment are placed. The top of this cavity is cloſed by means of a cover: the middle ſpace next to this is deſigned to contain the ice which ſurrounds the

 interior

interior copartment: this ice is ſupported and retained by a grate, upon which a cloth is ſpread; in proportion as the ice melts, water flows through the grate and the cloth, and is collected in a veſſel placed underneath. Laſtly, the external place or copartment of the apparatus contains ice, intended to prevent the effect of the external heat of the atmoſphere.

To uſe this machine the middle or ſecond ſpace is filled with pounded ice, as is alſo the cover of the internal ſphere; the ſame thing is done with regard to the external ſpace, as well as to the general cover of the whole machine: the interior ice is ſuffered to drain; and when it ceaſes to afford water, the covering of the internal ſpace is raiſed to introduce the body, upon which the experiment is intended to be made: the covering is to be put on immediately, and the whole apparatus remains untouched until the included body has acquired the temperature of 32, or the freezing temperature of water, which is the common temperature of the internal capacity: the quantity of melted water afforded by the melting ice is then weighed; and this may be conſidered as an accurate meaſure of the heat diſengaged from the body, becauſe the fuſion of the ice is the effect of this heat only. Experiments of this kind laſt 15, 18, or 20 hours.

It is of great conſequence, that in this machine there ſhould be no communication between the middle, or ſecond, and the external ſpace.

The air of the room ſhould not be lower than 32, becauſe the ice would then receive a degree of cold lower than that temperature.

As ſpecific heat is the quantity neceſſary to raiſe bodies to the ſame number of degrees of temperature; when the ſpecific heat of a ſolid body is required, it's temperature muſt be elevated a certain

a certain number of degrees; at which inſtant it muſt be placed in the internal ſphere, and there left until it's temperature is reduced to 32°: the water is then collected, and this quantity divided by the product of the maſs of the body; and the number of degrees of it's original temperature above 32°, will be proportional to it's ſpecific heat.

Fluids are incloſed in veſſels whoſe heat has been previouſly determined. The operation is the ſame as for ſolids; excepting that the quantity of water afforded, muſt be diminiſhed by a deduction of that quantity which has been melted by the heat of the veſſel.

To determine the heat diſengaged during the combination of different ſubſtances, they, as well as their containing veſſels, muſt all be reduced to 32; and then placed in the internal ſphere, and the quantity of water collected is the meaſure of the diſengaged heat.

To determine the heat of combuſtion and reſpiration, as the renewal of air is indiſpenſible in theſe two operations, it is neceſſary to eſtabliſh a communication between the internal part of the ſphere, and the ſurrounding atmoſphere: to prevent error, theſe experiments ſhould be made when the temperature of the air differs very little from the freezing point.

For gaſſes, a current muſt be eſtabliſhed through the internal part of the ſphere, and two thermometers are to be uſed; one at the place of introduction, and the other at the place of eſcape: by a compariſon of the temperatures exhibited by theſe two inſtruments, a judgment is formed of the heat abſorbed, and the melted ice is meaſured.

METHODS

METHODS OF MEASURING GREAT DEGREES OF HEAT.

As the degrees of heat can only be appreciated by it's effects; and as fluid thermometers can only be used in temperatures below their point of boiling, various instruments have been contrived to estimate the effects of heat; some of these have been already described: I shall now give you an account of one contrived by Mr. Wedgewood, for ascertaining the measure of the more intense degrees of heat.

The substance he uses for this purpose, consists of three parts of argillaceous earth added to two parts of the siliceous kind, which are well washed, &c. and then dried: this dry clay is softened by adding two-fifths of it's weight of water; and is formed into pieces by compressing it through holes of proper dimensions, in the bottom of a vessel; and when dry these pieces are exposed to the fire, and shew it's intensity by the contraction of their dimensions, which are ascertained by a gage made of two strait pieces of brass 24 inches long, divided into inches and tenths: they are fixed on a brass plate, so as to be six-tenths of an inch asunder at one end, and three-tenths at the other; so that one end of the pieces, when properly sized, just fills the wider end: if this piece be diminished by heat one-fifth of it's bulk, it will pass through one-half the length of the gage; if diminished two-thirds, it will pass on to the narrower end; and in any intermediate contraction, the degree at which the piece stops against the converging sides will measure it's contraction; each division of the scale answering to $\frac{1}{600}$th part of the breadth of the piece of clay.

Experiments by this Thermometer.

Degrees.	
156	Common Chineſe porcelain becomes ſoft.
150	A Heſſian crucible melted into a ſlag-like ſubſtance.
130	Caſt-iron melts.
125	Heat of a common ſmith's forge.
124	Vitrification of plate-glaſs.
114	Ditto of flint-glaſs.
121	Bow china, } vitrified.
112	Derby china, } vitrified.
105	Chelſea china, } vitrified.
102	Stone-ware, fixed.
95	Welding heat of iron.
86	Queen's ware, fixed.
32	Gold, } melted.
28	Silver, } melted.
27	Swediſh copper, } melted.
21	Braſs, } melted.
0	Red heat viſible in the day.

Dr. Martine, to obſerve the quickneſs with which bodies heat and cool, put an equal quantity of mercury and water into two diſtinct phials cloſely ſtopped; and found, upon putting them into boiling water, that the mercury received heat much ſooner than the water, and in greater quantity, and loſt it much ſooner, notwithſtanding it's denſity; hence the temperature of mercury is more eaſily raiſed than that of water. To know the equilibrium of heat among various ſubſtances, experiments muſt be made upon them; as it varies irregularly, and ſeveral of the metals require leſs fire to heat them than water: thus the ſame fire heats lead twice as much as water; or lead loſes and gains as 5 to 2; thus heat water and lead to the ſame point, and then two cubic inches of water will

will produce as much heat in cold water, as 5 cubic inches of heated lead would do in the ſame quantity of water. Tin and glaſs require half the quantity, or as 4 to 2: iron requires the ſame quantity as water; copper ſomewhat more: hence the intenſe heat of iron and copper when red-hot. On theſe principles Dr. Black had a method of eſtimating high degrees of heat: for having found that iron and water were heated equally by the ſame degree of heat, he took a piece of red-hot iron of a determinate ſize, and plunged it into 100 times it's bulk of water; and when the whole of the heat which was concentrated in the iron, was diffuſed through the water, he meaſured the heat of the water by a thermometer: this multiplied by 100, gave the heat of the iron when red-hot.

Sir Iſaac Newton thought that the progreſſion with which heat is communicated or loſt, is geometrical; Dr. Martine, that it is a compound of geometrical and arithmetical progreſſion. Dr. Black thinks the method of making experiments to inveſtigate this progreſſion, ſhould be by ſtreams of air and water paſſing off continually: thus the cooling cauſe would keep a conſtant equal progreſſion; but if the cooling medium of air or water be ſtagnant, the caſe is quite changed: on this principle depend the phenomena of air, which in ſtill calm weather ſeems warmer than in windy weather, though by the thermometer we find it the ſame: in calm weather our bodies make a kind of atmoſphere of their own, which is warmer than the ſurrounding atmoſphere. Air, when agitated, is not thereby made cooler; yet if you blow with a bellows on a piece of ice, it will melt ſooner than when not blown upon, becauſe you blow away a ſmall portion of air which the ice had cooled round it.

As the methods of making experiments on high degrees of heat are of the utmoſt importance,

I ſhall now lay before you the means uſed by the Rev. Mr. Jones for this purpoſe. His firſt attempt was with the inſtrument we uſed to exemplify the force of fire. To reduce it's motion to the ordinary ſcale of Fahrenheit, this bar (*fig.* 3, E, *pl.* 5,) was included in a braſs box, and was heated, together with a mercurial thermometer, by the application of boiling water; and when it appeared, by the index, that the bar had acquired as much heat as the water would communicate, the heat of the water was marked by the thermometer. By this means, he diſcovered what number of degrees in the graduated arch, anſwered to a certain number of degrees on Fahrenheit's ſcale; as the motion of the index was not equable in all parts of the arch, he aſcertained it's irregularities by the micrometer ſcrew and plate.

Two ſubſtantial iron heaters were made red-hot, and then applied in turn to the bar under examination; and thus the degrees of heat, at which the ſeveral colours appear on the poliſhed ſurfaces of *braſs* and *iron* bars, were readily obtained. The foregoing method not carrying Mr. Jones ſo far as he wiſhed to go, he then adopted another mode, founded upon this principle, That denſe fluids acquire heat ſooner than rare ones; water heats mercury more and quicker than mercury heats water. To render this evident, let us immerge theſe two thermometers, one made with ſpirits, the other with mercury: you ſee how ſluggiſh the ſpirits moved, and how ſoon the mercury acquired it's greateſt degree of expanſion: you may render this ſtill more evident by plunging an heated iron into an open veſſel of mercury: if you agitate the heated iron ſuddenly under the mercury, all the heat it is capable of receiving is communicated almoſt inſtantaneouſly.

Mr.

Mr. Jones ſuppoſes that the heats *communicated* to a given quantity of mercury by an immerſion of the ſame iron differently heated, will be to each other as the *original* heats in the iron itſelf. To obtain a datum, he firſt plunges a piece of iron, with a known degree of heat, into a given quantity of mercury, and obſerves the degree of heat communicated. Let us ſuppoſe, ſays he, the quantity of mercury in an iron veſſel to be 2 pounds, the heated iron a cylinder weighing 274 grains: this cylinder having the heat of boiling water 212° plunged into the mercury with a temperature of 52°, will communicate to it 10 degrees of heat, which is $\frac{1}{16}$ of that exceſs it had acquired: we ſay, then, that let the exceſs of heat in iron be what it will, the heat communicated to the mercury will always be $\frac{1}{16}$ of that exceſs; ſo that if we put t for the natural temperature of the mercury, h for the communicated heat, and x for the heat required, it will be $t \times 16\, h = x$. This method was ſo eaſy, that Mr. Jones preferred it to the former; with which, however, to his great ſatisfaction, it agreed as far as it extended. In determining the degrees this way, it was always taken for granted that the heated iron parts with all it's exceſs of heat to the mercury, and that the diſtribution is ſo nearly inſtantaneous, that it may be taken for ſuch without any material error. Some little time will inevitably be loſt, and therefore the heats obtained by this method of *mercurial immerſion*, eſpecially the greater heat near the extremity of the ſcale, will always be rather *under* than over-rated.

A SCALE OF HEAT.

	Fahrenheit's Degrees.
Iron in fuſion about	3000
Iron with the white ſparkling heat of a ſmith's forge	2780
Iron with a heat almoſt white	2080
The heat of live coals without blowing, perhaps about	1650
Iron with a glowing red by day-light	1600
Iron juſt red-hot by day-light	1120
Iron juſt red-hot in the dark	1000
Greateſt heat of lead in fuſion	820
Colours of iron are burned off	800
Mercury boils, by ſome placed at 600; by Jones	700
Poliſhed iron takes a full blue	700
Poliſhed iron takes a purple	660
Linſeed oil boils, by ſome at 600	620
Lead melts	610
Poliſhed iron takes a ſtraw colour	605
Oil of vitriol boils	546
Braſs takes a blue colour	500
Tin melts	490
Tin-foil and biſmuth	450
Braſs takes a copper colour	415
Poliſhed braſs takes a gold colour	340
Spirit of nitre boils	242
Water boils at a mean ſtate of the atmoſphere	212
Freſh human urine boils	206
Brandy boils	190
Alcohol boils	176
One pound of water of 52°, to ½ a pound of freſh chalk lime	182
1 oz. of water of 54°, to ½ oz. of oil of vitriol	170
Serum of blood and white of eggs harden	156
Bees wax melts	145
Greateſt heat of a bath which the hand can well bear	114

Heat

	Fahrenheit's Degrees.
Heat of the Serocco wind at Palermo in Sicily	112
Heat of an hen hatching eggs, from 92 to	108
Heat of the ſkin in ducks, geeſe, hens, pidgeons, 103 to —	107
Heat of the human ſkin in an ague fever	106
Heat of the ſkin in dogs, cats, ſheep, and other quadrupeds, 100 to —	103
Heat of the human ſkin in health —	98
Heat of a hive of bees —	97
Heat of the air in the ſhade in very hot weather	80
Butter begins to melt —	74
Temperate — —	55
Oil of olives begins to ſtiffen —	43
Water juſt freezing, or ice juſt melting —	32
Milk freezes — —	30
Urine and common vinegar freeze —	28
Good burgundy, claret, and madeira freeze	20
One part of ſpirit of wine, with 3 of brandy, freezes — —	7
A mixture of ſnow and ſalt —	0
Mercury freezes — —	39

With reſpect to the formation of this table, ſee Jones's Phyſiological Diſquiſitions; where you may alſo find a method of examining the ſcale by comparing the articles one with another. *

In the foregoing ſcale the heat of boiling water in vacuo is placed at 95°; this however will depend on the perfection of the vacuum and other circumſtances. In the Rev. Mr. Jones's experiments, a heater was placed on the plate of the air-pump, and on this a light tin veſſel holding the

* Mr. Wedgewood places ſome of theſe degrees much higher, but I muſt own I am not ſatisfied with the clay thermometer, and think there muſt be further and more ſatisfactory evidence adduced, before any one can agree with the degrees of heat deduced from it.

water and a thermometer. The ebullition in one experiment began to appear at 90 degrees, and as the boiling increaſed, the thermometer roſe to 105 degrees, where it ſtood when the agitation was moſt violent; the air was admitted during this agitation, and the thermometer immediately roſe 15 degrees. In another experiment, ſome water heated to 130 degrees was placed on the heater, and this being covered with a receiver, the air was exhauſted, on which the water boiled vehemently, but during the act of boiling, the heat ſubſided to 100, and at another to 94 degrees, but on admiſſion of the air, the heat preſently roſe to 130 degrees and upwards.

Theſe experiments prove, what has been already obſerved to you, how much *the action of fire depends on the reaction or preſſion of the incumbent air*. When the air is withdrawn, the fire naturally aſcending, flows through the liquor in the veſſel, as air would through a tube open at both ends. But if the farther end of this tube were cloſed, and the current of air ſtill to continue, it would be condenſed or accumulated within the cavity of the tube. Hence we may collect, that the ſun would heat the earth very inconſiderably, if it were not for the incumbent preſſure on it's ſurface, and that therefore it is impoſſible to calculate what the heat will be in bodies placed at different diſtances from the ſolar fire, unleſs we could tell how far air acted upon them at the ſame time.

The higher we aſcend, the leſs is the degree of heat, the atmoſphere is leſs ſuſceptible of heat as it is more rarified; as the intenſity of fire will naturally produce the greateſt heats, the lower parts of the atmoſphere ought to be hotter than the higher, where fire is leſs preſſed, and has more room to dilate itſelf.

It will be neceſſary, before we proceed any farther,

farther, to make ſome obſervations on *phyſical meaſures.* Moſt of our philoſophical inſtruments are meaſures of effects. The progreſs made in natural philoſophy increaſes every day by the number of theſe meaſures; by theſe it has reached it's preſent ſtate, and by theſe it ſtill continues to be improved. In proportion as the different branches advance, our *meters* are multiplied. Inſtead of being ſatisfied with perceiving, with conjecturing, with forming ſyſtems, upon what is improperly called the poſſible, but which is in reality the land of viſions; we now endeavour to inveſtigate cauſes through their effects, by meaſuring theſe wherever nature gives us ſufficient hold.

The firſt rays of this light, the dawn of true knowledge in philoſophy, were extremely weak. Philoſophers contented themſelves with having inſtruments which indicated the *exiſtence of certain cauſes* that *our organs could either not diſcover,* or *diſcovered very imperfectly.* Hence the modeſt names given to inſtruments by their firſt inventors, they called only baroſcopes, thermoſcopes, microſcopes, the inſtruments which were intended to ſhew the weight of the air, the dilatation of bodies by heat, the objects which eſcaped the naked eye.

Theſe names were too ſoon changed, and that of meaſures given to inſtruments that were not entitled to the name. Philoſophers grow every day more delicate with reſpect to the requiſite qualities of their inſtruments; the progreſs in perfecting theſe meaſures, is an effectual ſtep towards the knowledge of nature. The improvements in the meaſures, not only lead us to a better knowledge of the immediate cauſes of the effects thus meaſured, but they aſſiſt us alſo in decompoſing complex effects.

Indeed the greater part of phyſical inſtruments are

are intended only for the discovery of simultaneous effects, by the knowledge of those which are most evident. If we wish for an hygrometer, an electrometer, a photometer, it is not so much with a view of ascertaining by their means, the absolute or even relative quantities of moisture, of the electric fluid, or of light, as to *connect* the perceptible effects of moisture, electricity, &c. on our measures, with other less evident effects intimately connected with, or dependent on them.

The general problem of physical measures is complicated. The first object of these measures is to ascertain the *existence* and *agency* of a simple cause, and it's degrees of intensity; this we can only arrive at by it's action on other bodies, but in this action or effect many other causes are included. *We cannot observe simple effects*; and consequently we cannot always conclude from *sensible effects* which are equal amongst themselves, that the degrees are equal in the cause to which they are attributed. What for example do we use in general as measures of heat? The dilatations of various substances. What are the measures by which we determine the weight of air? The height of the mercury in the barometer. But the dilatation of bodies by heat, depends upon the nature of the substance, it's density, it's cohesion, the laws of it's progression by equal augmentations of heat, &c. The effects of the weight of the air upon the mercury in the barometer, are modified by the different degrees of heat in this fluid, by the nature of the vacuum in which it is suspended, by the attraction, by the friction, perhaps by the *permeability** of glass, to some particles of that mixed fluid, to which we give the general name of air, or to other unknown

* Mr. De Luc, Phil. Transf.

known cauſes: ſo difficult and complex is even the firſt ſtep of the ladder by which we endeavour to raiſe ourſelves to the knowledge of cauſes.

OF FLUIDITY, &C. AS EXPLAINED BY LATENT HEAT.

I have already obſerved to you, that all the ſubſtances in nature are either *ſolid*, *fluid*, or in the form of expanſible fluids: that theſe different forms depend principally on the ſtate or combination of fire in them, has, I think, been ſufficiently proved by reaſon and experiment; but it will be rendered ſtill clearer, by a view of modern diſcoveries, which I ſhall now lay before you.

Fluidity is an effect of fire, and takes place when the heat is carried to a certain height; and as bodies become fluid by the application of fire, ſo fluids preſerve their fluidity, by the fire they contain.

In fluidity, there is a conſiderable quantity of diſperſive, or expanſive matter introduced into the body, while the volume is not thereby increaſed. This introduced matter acts in another manner, ſo as to oppoſe the agency which cauſes ſolidity, or reſiſt the particular attachment of the parts.

Liquifaction is a looſening the parts of bodies by a certain degree of heat, which parts are fixed and ſolid with a leſs degree. It is effected by introducing fire between the particles, which ſeparates them from each other, and by it's activity gives them a free motion among themſelves.

Fire is reſident and active in all bodies, and at all times; but in order to render them liquid, it muſt act with greater or leſs force, according to the nature of the ſubſtance. We ſay of bodies naturally hard, when they become fluid, that they are *melted*; and of bodies naturally fluid, when they become ſolid, that they are *congealed*, or frozen; the effects

are fimilar in each cafe, and you will be juftified by philofophy in confidering all water as *melted ice*, and a pig of lead as a mafs of congealed metal. The fluidity of water is as real a fufion, as that of any metals expofed to the fire, differing only in this, that a greater quantity is neceffary for one than the other.

Liquifaction is a phenomenon, however, entirely diftinct from the *expanfion* or *dilatation* of a fluid already formed. This laft circumftance only occafions a greater or lefs degree of tendency in the particles towards each other, and varies with every variation in the degrees of heat. *Liquifaction* is occafioned by a certain fixed degree. Liquifaction is *a real change of ftate* in the fubftance, the degrees of expanfion are only *modifications* of the fame ftate. In expanfion, there is a regular increafe or decreafe of bulk according to the degrees of heat; whereas, in fluidity, the tranfition from a folid to a fluid, or *vice verfa*, is fudden; and above or below a certain degree of heat, a body always remains folid or fluid.

As nature is now conftituted, natural bodies, and their minuteft parts, may be confidered as floating in an ocean of what the poet calls *indefatigable fire*; an element which is moved with the fame vigour now as 5000 years ago; and the bodies fuftained therein are *hard* or *foft*, *folid* or *fluid*, *lax* or *firm*, *rare* or *denfe*, *expanded* or *contracted*, according to the changes in the temperature of this element, which keeps up a conftant fyftole and diaftole, through the whole frame of nature. If this motion of fire were to ceafe, univerfal rigidity and ftagnation would enfue; all the *qualities* of the ancient fchools, all the *attractions* and *repulfions* of later philofophers, would be buried in one common grave, and fixed with an impenatrable feal.

Of Latent Heat.

It is impoſſible thoroughly to underſtand the metamorphoſis of ſolids into liquids, and of liquids into aeriform fluids, without a knowledge of the doctrine of *latent heat*. Here you will learn that the *ſame* ſubſtance, according as it happens to be in any of theſe ſtates, not only poſſeſſes a different ſpecific heat, but modifies even in the act of paſſing from one to the other, the matter of fire in a very particular manner.

To *Dr. Black*, the father of modern chemiſtry, we are indebted for this diſcovery, which I ſhall firſt explain in a ſimple form, and then further illuſtrate it by the reaſoning and experiments which are attributed to Dr. Black.

Let us ſuppoſe a piece of ice cooled until a thermometer placed therein ſtands at 20° below the freezing point, expoſe this ice to a conſtant emanation of fire, arriving by very equal degrees, the thermometer will riſe very uniformly till it comes to the freezing point, and will there ſtop, although the igneous emanation continues the ſame, and ought apparently to continue raiſing the temperature.

This current of fire, which arrives unceaſingly and by degrees at the ice, has no longer any ſenſible effect on the thermometer, for as ſoon as the thermometer is thereby raiſed to the freezing point, the effect of the fire is limited, and it only exerts itſelf in making the *ice change it's ſtates*, by converting it into water; and during the whole of this transformation the thermometer remains ſtationary at 32 degrees, the freezing point.

The fire in this caſe loſes, as it were, it's faculty of heating; yet the quantity employed, and apparently loſt in this transformation, is ſo conſiderable,

able, that if the thermometer under the ſame circumſtances, were placed in a ſimilar quantity of water inſtead of ice, it would have riſen near 120 degrees.

As ſoon as the fuſion is completed, if the ſame igneous emanation continues, the thermometer now actually in water, will be influenced by the fire as it arrives, and will riſe ſucceſſively; though ſomewhat ſlower than before, becauſe the ſpecific heat of water is a little greater than that of ice.

The thermometer continues to riſe till it arrives at the boiling point, and here again the ſame phenomena occur. Notwithſtanding the continuation of the igneous emanation, the thermometer remains at 212 degrees, and the water now *changes it's ſtate*. It is transformed into an elaſtic fluid, and the portion of fire, which, by it's momentary union with the water, effected it's change, loſes it's *thermometric quality*; and an exact equilibrium is eſtabliſhed between the *afflux* of additional fire, and it's *efflux*, by the converſion of water into an elaſtic vapour.

The fire thus modified has been called *latent*. It is truly hidden or latent, but manifeſts itſelf again, and it's action is rendered evident, if you reverſe the changes; that is, if you convert the elaſtic fluid into a liquid, and the liquid into a ſolid.

Dr. Black was the firſt who ſhewed that fluidity, though depending upon fire, did not depend upon the quantity indicated by the thermometer, but upon the *abſorption* and *combination* of fire with the ſubſtance rendered fluid; and the quantity thus abſorbed, he denominated *latent heat*, as being imperceptible to us, but ready to immerge on proper occaſions and aſſume a ſenſible form. By *ſenſible heat*, he means the fire which is

ſo

ſo far in a fluctuating ſtate, that if you apply any ſubſtance which contains an exceſs of it, to a cooler one, it quits the hotter, and flies to the cooler ſubſtance, ſo as to reſtore an equilibrium. You know very well, that as long as a body continues ſolid, if the heat thereof be increaſed, it is always perceptible by the thermometer. But if you ſuppoſe a body heated as much as it can bear, and ſtill continue ſolid, then every degree of fire thrown in afterwards is abſorbed and becomes *latent*, or is put into ſuch a ſtate as cannot be diſcovered by the thermometer, but goes to make the body fluid, and as ſoon as a ſufficient quantity is abſorbed to make every part fluid it will admit of, and manifeſt a ſenſible increaſe of heat. It was alſo obſerved by Dr. Black, that bodies are not diſpoſed to abſorb this latent heat, until they arrive at their melting point, nor fluids to part with it until cooled to a certain degree. If after this, they are placed ſtill nearer cooler bodies, this latent fire continues immerging, and the body becomes ſtill more ſolid; when the whole is entirely extracted, the body freezes. Hence when the latent fire is extracted, the body is of the ſame temperature with the ſurrounding medium.

This luminous doctrine Dr. Black ſupported by a reference to phenomena, and by well deſigned experiments. It is confirmed by conſidering the ſlowneſs with which ice and ſnow melts, when a thaw comes on, and when the heat is far above the degree of froſt; for the ice is conſtantly ſurrounded with air warmer than itſelf, and receiving heat from it, yet it will be weeks in diſſolving. If nothing more was neceſſary to produce fluidity than the fire indicated by the thermometer, we might reaſonably expect that after it begins to melt, one or two days would be ſufficient to melt the whole. But, as it is ſo long diſſolving; and it's heat is not increaſed

increaſed above the freezing point, nor the water that runs from it above 32 or 33 degrees, it is plain, that the heat or fire to which it is expoſed muſt be abſorbed and become latent. It is to this cauſe you muſt attribute the preſervation of ice in ice-houſes, and that large maſſes of ice and ſnow remain at the tops of mountains, where heat is conſiderably above the freezing point.

Dr. Black's experiments will, I think, convince you, that the fluidity of water muſt be attributed to an abſorption of fire. To prove this, he endeavoured to determine the heat abſorbed by *ice* during it's *liquifaction:* this he obtained by obſerving the quantity of heat which was communicated by a maſs of ice during it's fuſion by the temperature of the air alone; and then inverſely, by diſcovering the quantity of heat, a maſs of *ice* took from a quantity of water, by mixing known quantities of ice of a given temperature, and water of a given heat together. Thus he took two Florence flaſks of equal ſhape, ſize, and weight, cutting off their necks and part of their bulbs, that he might be able to introduce a thermometer. In one he put 5 oz. of ice, in the other the ſame quantity of melted ſnow, nearly of the ſame temperature with the ice. Thoſe flaſks were ſuſpended by wires in the middle of a large room, to which nobody had acceſs but himſelf, and whoſe temperature was 47 degrees by a very ſenſible thermometer, which aſſumed the temperature in half a minute; he found that in half an hour the mercury in the latter had riſen 6 or 7 degrees, only a ſmall quantity of ice was melted, and though it had received near 7 degrees of heat, yet it continued at the freezing point. The flaſks were left all night; on returning in the morning, at about 10 hours and a half from the commencement of the experiment, he found a piece of ice undiſſolved as

as big as a nut in the middle of the ſurrounding water, which, by the thermometer, was 8 degrees above the freezing point.

From this we may calculate the degree of heat the ice muſt have received before it melted, (remembering that the air was at 47 degrees,) obſerving that the ice muſt have been receiving heat gradually.

At the end of 10 hours and an half the thawed ice was juſt at the temperature at which the melted ſnow was at the end of half an hour; the melted ice muſt therefore have received 7 degrees every half hour, ſo that in 10 hours and an half it muſt have received juſt 147 degrees. That the flaſk was continually receiving fire from the air, was confirmed by a cold ſtream being perceived from the bottom of the flaſk; this was the air which had been applied to the flaſk, and had imparted it's fire to it, and, being cooler and denſer, preponderated. This ſhews that the ice was continually receiving fire, though not ſenſible or manifeſted by the thermometer, and muſt therefore be combined therewith and become *latent fire*.

The doctor having before found that a mixture of hot and cold water produced an arithmetical mean between them, he took a determinate quantity of ice, and put it into a Florence flaſk, and threw exactly the ſame quantity of boiling water upon it, which melted the ice inſtantly, and all at once, proving thereby, that there is no difficulty of ſeparating the particles of ice, if a ſufficient quantity of heat be applied. But, upon examining the temperature of the mixture, it was found much lower than if cold water about the freezing point had been uſed inſtead of ice; and that it loſt the ſame quantity of heat, 147 degrees, which the ice in the former experiment required to render it fluid; for in this it fell

68 degrees below the mean; the ice abſorbing ſo much fire from the boiling water, that the mixture did not point to the mean as it would have done if cold water had been uſed inſtead of ice, but to that point which ſhewed that the ice, in order to become fluid, muſt be combined with ſo much fire as would, if liberated, raiſe the thermometer 147 degrees. Theſe two experiments differ only in this, that one was made with warm air, the other with warm water. Again; if a pound of water at 32 degrees be mixed with an equal quantity of that fluid at 172 degrees, the temperature of the mixture will be 102 degrees, the arithmetical mean between the warm water and the cold. But if a pound of ice at 32 degrees be mixed with a pound of water at 172 degrees, the temperature of the mixture will be 32 degrees.

It appears clearly from this experiment, that ice and water both being at 32 degrees, are very differently affected by fire; for, in the firſt of the two foregoing experiments, a quantity of fire which raiſed the thermometer 70 degrees, paſſed from the warm into the cold water, and the temperature of this was increaſed 70 degrees. In the laſt experiment, a quantity which raiſed the thermometer 140 degrees paſſed from the warm water into the ice, in conſequence of which the ice was melted, but it's ſenſible heat was not increaſed, the temperature of the mixture being 32: ſo that in the proceſs of liquifaction, or melting the ice, 140 degrees of the heat are abſorbed, not producing any effect upon the thermometer. Theſe experiments, and the deductions from them, are further confirmed by ſhewing that a quantity of heat emerges from water when it paſſes from a fluid to a ſolid ſtate, which can only ariſe from the latent fire.

If you expoſe water to freeze, putting a thermometer into it, the water being 20 degrees

warmer

warmer than the air, it will loſe a great many degrees during the firſt five minutes, leſs the next, and ſo on; in half an hour, if the air be below the freezing point, it will have attained the temperature of the air, and you would ſuppoſe that in 2 or 3 minutes all of it would freeze, which would be the caſe if it depended on a diminution of thermometric fire; but it is not the caſe, for you will find at firſt a ſmall part of it freezing, and gradually increaſing in the congelation: during this time the water will continue at 32 degrees, which is perhaps one or two degrees above the temperature of the air to which it may be expoſed. Now as a colder body, if it be applied to a warmer one, will ſoon become of the ſame temperature with the air to which it is expoſed; we can only attribute the water not becoming of the ſame temperature with the air to which it is expoſed, to the *latent fire* emerging and manifeſting itſelf as ſoon as any particle of the water freezes; and as ſoon as this is all exhauſted, the maſs becomes ſolid, and of the ſame temperature with the air.

If water be at reſt, it may be cooled 7, 8, 9, or 10 degrees below the freezing point without being congealed; but if touched with a bit of ice, the end of a wire, or if the veſſel be agitated, the congelation pervades it like a flaſh of lightning. Mr. Mairan expoſed ſmall drinking glaſſes full of water, theſe were cooled below the freezing point, and yet would, if left undiſturbed, remain ſo, but upon being agitated froze immediately. If a thermometer were put into the water during the freezing, the moment it was frozen, it *roſe up* to the congealing point, a quantity of latent fire emerging from the water. Here you ſee a quantity of *latent fire* emerging ſuddenly, and the experiment ſhews that this does not altogether depend on the diminution of ſenſible heat, ſince we find the

 water

water retains it's fluidity, though cooled 7 or 8 degrees below the freezing point.

The fire abſorbed by the water when it acquires *fluidity*, is again ſeparated by *congelation*. If a pound of water at 32 degrees be mixed with an equal quantity of ice at 2 degrees, nearly one fifth of the water will be frozen, and the temperature of the mixture will be 32: it is therefore plain that by the congelation of nearly one fifth of a pound of water, *a ſufficient quantity of fire was extricated to raiſe a pound of ice 30 degrees;* and by calculation, you will find that the heat which is extricated by the congelation of water, is preciſely equal to that which is abſorbed by the melting ice.

The heat extricated in the freezing of water, ſhews why that fluid, when it is expoſed to a degree of cold lower than 32 degrees, and is at the ſame time gently agitated by the wind, ceaſes to cool as ſoon as it arrives at the freezing point, the temperature thereof continuing ſtationary until the whole is congealed; it being well known that 32 degrees is the point at which water in a gentle ſtate of agitation becomes ſolid. When therefore it is reduced to that point, it begins to freeze, and part with it's fire; and as the extrication of fire in this inſtance depends upon the congelation, it is clear that the quantity of fire extricated will be in proportion to the quantity of water congealed.

In other words, if when melted it is allowed to cool ſlowly with a thermometer immerſed in it, you will find that as long as it continues fluid, the ſenſible heat diminiſhes very faſt, but as ſoon as it begins to grow ſolid, the ſenſible heat continues greater than that of the air to which it is expoſed; and during all this time it is communicating heat to the air, without having it's ſenſible heat diminiſhed: the latent fire within the fluid gradually manifeſts itſelf, and by keeping up

up the temperature, proves a ſource of ſenſible heat which is communicated to the neighbouring bodies and ſurrounding air.

Dr. Irvine has ſhewn, that when ſpermaceti and wax are melted they contain this latent fire; for by heating them much above their point of fluidity, he found they loſt their heat very ſoon, till ſome parts became ſolid; after this they continued of exactly the ſame temperature till the whole became ſolid, though expoſed all the while to cold air; but when all became ſolid, they cooled as they did at firſt. Spermaceti abſorbed from 141 to 148 degrees to become fluid, wax 175. He put a certain quantity of melted tin into water, and an equal quantity of tin heated to the ſame degree, but not fluid, into a like quantity of water, and the water was heated moſt by the melted tin, the latent fire emerging therefrom.

If the nitrous acid be mixed with ice or ſnow, there will be a ſudden liquifaction. Mixtures in general promote liquifaction, and in this inſtance *a moſt intenſe cold* is produced, which is eaſily explained on the foregoing principles: if you liquify ice, you muſt throw in a prodigious quantity of fire, which immediately becomes latent in the liquid, and is not diſcoverable by a thermometer. By producing a *ſudden* liquifaction of ice, the cold is ſo great, that all the neighbouring bodies muſt communicate of their fire to ſupply that which is to become latent by the liquifaction, and thus generate the cold we perceive.

The principle of latent fire explains alſo the curious phenomena of artificial cold, produced in the mixture of ſnow, water, and ſalt, as every body which paſſes from the ſolid to the liquid ſtate abſorbs a quantity of fire which does not affect the thermometer; hence cold is produced in the diſſolution of all the chryſtalized ſalts. The fire being

combined with the particles to keep the mixture fluid, and being only exerted thereon, the mixture becomes ſenſibly colder.

Upon theſe principles you may account for the large quantities of ice which remain on the ſurface of the earth ſome days after a thaw has commenced; for though each piece of ice is affected by the warmth of the atmoſphere, and the influence of the ſun, it cannot be immediately melted thereby, the ice abſorbing gradually all the fire communicated to it, till it has received ſufficient to maintain itſelf in the form of water. In the ſame manner you ſee why the ice in ice-houſes is not melted, which it would be, if all the fire which it received acted upon it to raiſe the temperature; which it does not do, being abſorbed, to contribute to it's exiſtence as water, and loſing therefore it's diffuſive action.

Dr. Crawford ſhews us, that by the laws of abſorption and extrication of fire, *Divine Providence* has wiſely guarded againſt very ſudden viciſſitudes of heat and cold upon the ſurface of the earth.

For if fire were not extricated by the proceſs of congelation, all the waters which were expoſed to the influence of the external air, when it's temperature was reduced below 32 degrees, would ſpeedily become ſolid; and at the moment of congelation, the progreſs of cooling would be as rapid as it was before the air arrived at that point.

But as ſoon as the atmoſphere is cooled below 32 degrees, water begins to freeze, and at the ſame time to give out the fire combined with it; and conſequently whatever may be the degree of cold in the external air, the freezing maſs remains at 32 degrees, until the whole is extricated and congealed; and as the quantity of fire that is liberated in the freezing of water is conſiderable, the progreſs of congelation in large maſſes is very ſlow.

Hence

Hence in the northern and ſouthern regions, upon the approach of winter, a quantity of fire is extricated from the waters proportional to the degree of cold that prevails in the atmoſphere; thus the *ſeverity* of the froſt is *mitigated*, and it's *progreſs retarded*. And it is highly probable, that during the retardation of the cooling proceſs, the various tribes of animals and vegetables, which inhabit the circum-polar regions, acquire the power of reſiſting it's influence.

On the other hand, if on the melting of ice a quantity of fire was not abſorbed and rendered leſs active, that ſubſtance, when expoſed to a medium warmer than 32 degrees, would ſpeedily become fluid, and the progreſs of heating would be as rapid as if no alteration in the form had taken place. If things were thus conſtituted, the vaſt maſſes of ice and ſnow, which are collected in the frigid zones, would, upon the approach of ſummer, ſuddenly diſſolve, and the regions near the poles would be annually overflowed by violent inundations.

But by the operation of this law of the abſorption of fire, when the ice and ſnow upon the return of ſpring have arrived at 32 degrees, they begin to melt, and at the ſame time to imbibe fire, which by being combined with the water does not act externally; ſo that the earth is ſlowly heated, and thoſe gradual changes are produced which are eſſential to the preſervation of the animal and vegetable kingdoms.

The mind of man admits with reluctance the truth of every teſtimony concerning matters of fact, which happen to be repugnant to the uniform experience of his ſenſes; hence the general backwardneſs to believe the miracles in the Bible: and hence the Dutchman, who informed the king of *Siam* that water in his country would ſometimes in cold weather be ſo *hard*, that men walked upon it,

 and

and that it would bear an elephant, was esteemed a person unworthy of credit. Hitherto, says the king, I have believed the strange things you told me, because I looked upon you as a sober man, but now I am sure you lie.

Mahine, the native of *Borabora*, could scarcely be persuaded even by the information of his senses, of the reality of the same effect. The appearances of *white stones*, as he called hail, which melted in his hand, was altogether miraculous to him; and when he had been, with difficulty, convinced that an extensive field of ice was not common land, he was determined, at all events, to call it *white land* to distinguish it from the rest.*

This determination of the savage was made in the true spirit of philosophy, for ice in small particles is a species of earth, and in solid masses it may be considered as a species of transparent stone. The *waters*, says Job, speaking of the effect of frost, *are hid as* with *a stone;* that is, water, when it becomes ice, conceals it's nature by assuming a stone-like hardness and consistence. The Russians applied ice to the same purposes with stone, at the marriage of Prince Gallitzin, in 1739; an house, consisting of two apartments, was built with large blocks of ice; the furniture of the apartments, even to the nuptial bed, was made of ice; and the icy cannon and mortars, which were fired in honour of the day, performed their office more than once without bursting.

Having already told you that I consider religion as the *firmest and only support of the happiness of man*, you cannot be surprized that I take every opportunity to fix your attention upon objects that lead you to it's AUTHOR, and consequently the consideration of final causes is continually interwoven with these Lectures.

The

* Watson's Chemistry.

The arguments for the being and providence of the Deity, deduced from the clear marks and signatures of wisdom, power, and goodness in the constitution and government of the world, will gather strength as your knowledge advances. When you attend to the marks of good contrivance, which appear in the works of God, every discovery you make in the constitution of the material and intellectual system becomes a hymn of praise to the great Creator and Governor of the world.

Though no man ever called in question the principle of final causes, when applied to the actions and discourses of men; for this would have been to deny that we have any means of discerning a wise man from an idiot, or a man that is illiterate in the highest degree, from a man of knowledge or learning; yet in all ages there have been those who, being unfriendly to religion, have denied the force of the proof: but you may depend upon it, that none will reason so absurdly, but the *philosophers of vanity, in whom the affectation of wisdom joins the extremity of folly.*

Fix upon two or three subjects which are clear beyond dispute, as that the *eye* does not see by *accident*, but was contrived for seeing, &c. and you answer all the atheists that ever were or will be; for you prove, by a single step of reasoning, that there is a DIVINE MIND OR WISDOM that hath wrought with a view to certain *ends*, which it hath attained in the most perfect manner.

Leaving these men, let me introduce you to a philosopher of a neighbouring nation, * who to soundness of judgment, joins strength of genius. Let us hear him speak on this interesting subject. I love, says he, to enumerate in my mind the impressions that I every where find of a beneficent hand;

* M. De Luc's Lettres Physiques et Morales sur l'Histoire de la Terre, p. 109.

hand; I am ignorant how it formed the world, but I do not make my happineſs conſiſt, in ſatisfying curioſity about an object evidently ſurpaſſing the reach of human ability. I love to feel, that I am not left to be the ſport of blind cauſes, without reſource againſt the fear of evil, without any certainty of the duration of good.

The immediate and durable conſequence of each moment of attention on the phenomena of nature, is infinitely more delightful to my mind, than that which I receive by the ſolution of a phyſical problem. It is a pleaſure that penetrates to the intimate eſſence of the ſoul; it is a kind of delicate love, or rather it is the ſupreme degree thereof, being excited by the contemplation of that Being who is GOODNESS and BEAUTY, and which taking poſſeſſion of the heart, fills it with gratitude, admiration, and hope.—Let us accompany this philoſopher in his meditations, on a ſubject which has already made part of this Lecture. I had made, ſays he, the thermometer my particular ſtudy, and in the courſe thereof, I endeavoured among the fluids in *uſe, to find one whoſe dilatations are the moſt proportional to the augmentation of heat which occaſions them.*

This queſtion would not have occurred, if the dilatation of each fluid, though different in quantity, had been proportional in it's progreſs. This was found clearly not to be the caſe, by comparing the march of a *ſpirit* thermometer with one of *quickſilver*. The compariſon ſhewed that their march was ſo different, that they could not be made to correſpond together, otherwiſe than by making the degrees of the one unequal, while thoſe of the other were equal. They muſt go in an increaſing progreſſion, beginning at the bottom and proceeding to the top of the ſpirit of wine thermo-

 meter,

meter, but from the top to the bottom of that of quickſilver.

As there was a different march in their progreſſion with the ſame augmentation of heat, it was clear, that one or the other was not proportional to the augmentation of heat. From hence a doubt originated, whether there was any fluid which dilated in proportion to the degrees of heat. In a courſe of experiments, to aſcertain this point, by comparing the march of different fluids with that of mercury, I was ſtruck, ſays our author, with the diſproportion between the progreſſion of water and that of other fluids. If you divide into 800 equal parts, the augmentation in the bulk of water and mercury in paſſing from the freezing to the boiling point, and if you compare the correſponding degrees of this augmentation in each fluid, you will find, that from the heat of melting ice to the greateſt degree of heat which reigns on the ſurface of the earth, when vegetation commences, (which I ſuppoſe 10 degrees of a thermometer divided into 80 parts) the mercury undergoes 100 of theſe 800 parts, and the water only 2. That from this point, to that which reigns only in ſummer, (that I ſuppoſe to be 25 degrees) the mercury dilated itſelf 150 of the 800 parts, water only 71; ſo that in the great heats of ſummer mercury has acquired 250 of it's 800 parts of augmentation, water only 73. Thus water does not aſſume in it's dilatations, degrees proportional to the augmentation of heat, the firſt degrees being very ſmall when compared to the laſt.

This was, without doubt, a very intereſting phenomenon. Having reflected upon the cauſe, framed an hypotheſis, and endeavoured to verify it by an experiment which ſucceeded, I received, I believe, as much pleaſure, as *phyſical* ſpeculation can give. I have publiſhed the hiſtory of this reſearch,

ſearch, but of the pleaſure I received, I have only a feeble remembrance.

Having, however, one day conſidered, that water is the fluid the moſt generally diffuſed in our globe, that all ſubſtances contain it, that it is the vehicle of all vegetable and animal nouriſhment, that it is included in all the veſſels that convey their food; that in all theſe reſpects, if it had been a turbulent fluid, rapid in theſe lower dilatations, the whole conſtitution of things would have been overturned: when this occurred, my mind was filled with admiration, I felt myſelf in poſſeſſion of a real treaſure, and I never think on the ſubject but with the utmoſt delight.

Do not then ſuffer yourſelves to be deprived of theſe delights; the ſearch after truth can only be ſalutary to you, when conſidered as proceeding from *a firſt intelligent* and *beneficent cauſe:* without this as an object of purſuit, ſhe loſes her moſt ſtriking beauties, all that can intereſt curioſity, or animate inveſtigation.

When you conſider the proceſſes in nature, from the moſt obvious effects to their moſt remote cauſes, ſo far as they fall within the ſcope of our comprehenſion, you find them one produced from the other in the moſt wonderful and regular ſucceſſion; that which appears the cauſe of one thing being the effect of another, and the whole together and each individual dependent in themſelves, incapable of producing any thing except as acted upon by others; all ſpeaking *the ſame language*; AN INCAPACITY, an ABSOLUTE INABILITY in themſelves of doing or cauſing any thing, and pointing you to a cauſe, diſtinct from all, an intelligent, active, powerful Being, who employs them for wiſe and gracious purpoſes.

Thus, a little attention to the nature of religion, will ſoon convince you, that *infidelity* and *irre-*

irreligion afford very few topics, on which a reflecting mind can dwell with pleaſure, even for a moment. You will find that infidels have not *one* argument on their ſide. For with all their pretences to reaſon and wiſdom, they can no more ſhew you, that you are not immortal, than they can ſhew you what was doing before the creation of the world. In ſuppoſing that the *whole* of your exiſtence ends with your body, they are as well ſupported, as they would be, in ſuppoſing that there are no beings but what are viſible to your eyes. In ſuppoſing that man will never be called to an account, they have no more reaſon, than you can have for ſuppoſing that there will be nothing a thouſand years hence.

Yet theſe are the *ſtrong foundations* of infidelity and prophaneneſs; theſe the ſolid principles of our *ſoi-diſant* philoſophers and their deluded followers.

If you inquire the characters of the moſt noted infidels, you will find them to have been men who exceeded their fellow creatures in nothing but *arrogance* and *preſumption*, and that infidelity in general is founded on an *implicit faith* in the writings and opinions of men of wanton and ſenſual minds. Yet theſe are the men who call our faith mean, and ſubmiſſion to revelation ſlavery, though yielded only to the higheſt evidence on matters of the greateſt moment.

Theſe men are very forward to tell you preciſely what God can or cannot do; he cannot work a miracle, cannot give a revelation, cannot guide the motions of a free agent, nor make ſuch a one impeccable, nor annex rewards to an aſſent of the mind, nor, &c. &c. For all theſe are contrary to the nature of things. If you aſk what things they mean, or what by the nature of them, they will not vouchſafe, or rather cannot give an explanation, but are angry with you as a captious perſon for putting the queſtion. They ſtill, however, go on to

lay a mighty ſtreſs upon theſe words, without having any clear or ſettled idea of their import. Theſe men are ſevere upon others for uſing expreſſions they do not underſtand. But believe me, you will conſtantly find them pretending to build demonſtrations upon principles, whereof they have no clearer, nor more adequate ideas, than the vulgar, whom they affect to ridicule, have of their myſteries; and you will find them *always endeavouring to make a conſtant repetition of poſitive aſſertions*, paſs for proof and explanation.

They wiſh to be conſidered as unbelievers, but on examination you will find them men of the moſt reſigned and implicit faith. The creed of the infidel has as many articles as that of the chriſtian, and the belief thereof requires a much greater ſuſpenſion of your reaſon. If to believe things upon no authority, or without any reaſon, be a ſign or mark of credulity; of all men, the free-thinker and infidel will be found to be the moſt eaſy and credulous. The difference between the chriſtian and the deiſt, does not conſiſt in this, that the one aſſents to things unknown, and the other does not; but in this, that the chriſtian aſſents to things unknown, on the account of evidence; the other aſſents to things unknown, without any evidence at all.

RELIGION requires a *ſerious* and *wiſe* uſe of your *reaſon*, and can only recommend itſelf to you when you are in a diſpoſition to reaſon and think ſoberly, and conſider it as the moſt ſerious, important, and ſacred ſubject in the world. It is not the deiſt's buſineſs to reaſon ſoberly, and conſider the weight and moment of things with exactneſs: idle ſtories, rude jeſts, and lewd inuendoes ſerve the purpoſe of infidelity, much better than any arguments it has yet diſcovered. They not only confuſe and diſtract the mind, but they alſo gratify and engage the

the attention of immoral men, by affording them what they deem an easy confutation of religion.

The objections of infidels are weak, and can have little force but upon depraved minds, or on those whose understandings are naturally weak, or made so by an implicit resignation of their faculties, to writings which can neither improve your mind, purify your heart, exalt your virtue, or increase your wisdom.

To doubt cautiously, till you have examined fully, and retain your assent till you have seen clearly, are proofs of reason and force of mind. But to doubt without any reason of doubting, is as great a defect as to believe without any reason of believing. Both extremes proceed from an excess of imagination, which disordering the intellectual eye, deludes the credulous *to see what is not*, and blinds the infidel, so that *he does not see what is*. There is a fundamental maxim closely connected with these observations, and that cannot be too strongly inculcated on your minds; for want of attention thereto, weak reasoners have imposed upon themselves, and deluded others. *Many things may be incomprehensible and yet demonstrable; and though seeing clearly be a sufficient reason for affirming, yet not seeing at all can never be a reason for denying.* We see many things must be, but we cannot conceive how they are. We see the connection between some truths, but not between all; we see a part, but not the whole; we see some attributes and modes of things, but we do not see their intimate essence. Nature abounds in mysteries, of which we may have a certain knowledge, but no clear conception; some are too large for imagination to grasp, some too minute for it to discern, others too obscure to be seen distinctly, and others, though plainly discernable in themselves, yet remain inexplicable in the manner of production, or appear incompatible with one another.

LECTURE

LECTURE VIII.

OF FIRE.

SO great is the power, ſo extenſive the action, and ſo wonderful the manner wherein *fire* acts, that it was anciently held and adored as the ſupreme God by a nation reputed the wiſeſt of all others. Thus ſome of the chemiſts having found it's extraordinary force, took it for an uncreated being, and many among them attributing all the knowledge they had acquired to this inſtrument, called themſelves *the philoſophers of fire*, thinking they could not be dignified by a higher title.

The phenomena of fire are ſo ſingular, and it's effects are ſo aſtoniſhing, as not eaſily to admit a compariſon with other appearances in nature; and if ever underſtood, it will be by means of experimental inveſtigation. Of this you will have a proof in the next ſubject of our diſcourſe, which is on *evaporation*.

Heat and cold, ſays Lord Bacon, are the *very hands of nature* with which ſhe chiefly worketh, the one contracting, the other expanding bodies, ſo as to maintain an oſcillatory motion in all their parts. So ſerviceable are theſe changes, that they are promoted every year, every day, every hour, every moment; all things co-operating to this work, night and day, light and darkneſs, ſummer and winter.

That a ſmall increaſe of heat expands air, and that it is hence in continual motion, will be proved by this ſimple inſtrument, which at the ſame time gives you ocular demonſtration of the *unintermitting agency of fire* on air, by ſhewing you that this fluid is never at reſt, but inceſſantly vibrating.

The

The inſtrument is nothing more than a Florence flaſk, containing about 2 ounces of ſpirit of wine, furniſhed with a tube 4 or 5 feet long, of a ſmall bore; the lower end of the tube is dipped below the ſurface of the liquor, but not ſo as to touch the bottom; a graduated ſcale is annexed to the tube. The juncture of the neck is made air-tight by a collar of metal and hard cement. The quantity of air being ſo large, and the tube ſo ſmall and long, you have a curious thermometer, which if expoſed at an open window will never be at reſt, ſhewing you that the temperature of heat is continually changing with every breath of air and paſſing cloud.

OF EVAPORATION.

According as the texture and denſity of fluids vary, the paſſage of fire through them is more or leſs retarded: hence as fire, in eſcaping, carries off a portion of the fluid with it, ſome fluids are more diſpoſed to *evaporate*, or fly off in vapour, than others; thoſe are called *volatile*, whoſe particles fly off with a ſmall degree of heat.

This general effect of fire cannot have eſcaped your notice, as it is obſervable in the moſt common occurrences of life. You continually ſee water going off in the form of vapour from a tea-pot, a tea-kettle, &c. If you put a ſmall quantity of water into a tea-kettle, and place it on the fire, it will diſappear in a ſhort time, having eſcaped in the form of vapour. This vapour or ſteam will, upon the addition of more heat, if it be not allowed it's proper range, expand with ſuch force as to burſt the veſſel in which it is confined.

If the ſteam of boiling water be at liberty, the water never attains more than a certain degree of heat; but if it be confined in a cloſe veſſel, the additional fire not eſcaping, the elaſticity of the ſteam is in-

 creaſed,

creaſed, it re-acts upon the water, raiſes the heat ſo much higher, that it may be made to keep lead in fuſion, and ſo penetrating, that it will ſoften in a few minutes the marrow-bone of an ox.

The inſtrument contrived for the foregoing purpoſes, (*fig.* 6, *pl.* 5,) is called *Papin's digeſter*, from the name of it's inventor, and from it's penetrating and diſſolving the ſubſtances that are expoſed to it's action. It is a ſtrong veſſel uſually made of copper, and fitted with a thick cloſe cover, which is faſtened down by ſeveral ſcrews, ſo as to be ſteam-tight in great degrees of heat. To render it ſafe, when uſed, there is on the cover a valve to let out the ſteam when too violent; this valve is kept down by a ſteelyard, and a weight moveable upon it, to regulate the degrees of ſtrength of the ſteam within.

The following account of an accident with one of theſe inſtruments, will give you ſome idea of the force of ſteam: Mr. Papin having fixed all things right, and included about a pint of water with two ounces of a marrow bone; he placed the veſſel horizontally between the bars of the grate, about half way into the fire; in three minutes he found it raiſed to a great heat, and perceiving the heat in a very ſhort time become more raging, he ſtepped to the ſide-table for the iron wherewith he managed the digeſter, in order to take it out of the fire, when on a ſudden, it burſt as if a muſket had gone off. A maid that was gone a milking, heard it at a conſiderable diſtance, and the ſervants ſaid it ſhook the houſe. As he had foretold, the bottom of the veſſel, that was in the fire, gave way; the blaſt of the expanded water blew all the coals out of the fire over the room, the remainder of the veſſel flew acroſs the room, and hitting the leaf of a table made of inch oak plank, broke it all in pieces,

pieces, and rebounded half way of the room back again. He could not perceive the leaſt ſign of water, though he looked carefully for it; the fire was quite extinguiſhed, and every coal black in an inſtant.

If a drop of water be placed on the bottom of an exhauſted receiver, it will ſuddenly diſappear, and be converted into a ſubtil vapour, which will fill the veſſel, and it's preſſure againſt the internal ſurface will be ſo ſtrong, when heated to a certain degree, that it will be almoſt impoſſible to confine it, and it will often burſt the veſſel with a loud exploſion. This effect of vapour is ſufficiently and readily exemplified by the ſmall machines called candle-balls. This great expanſion of the vapour is the true cauſe of the danger of throwing water into boiling oils, or upon melted metals, more eſpecially braſs or copper; the water being a heavier fluid than the oil, falls to the bottom, where it is immediately converted into vapour, and cauſes a violent ebullition. A ſmall quantity of humidity, when mixed with hot metals, will be converted into vapour with ſuch rapidity as to produce a more violent exploſion than gunpowder; hence the danger in caſting copper or iron veſſels; for if the fluid metal meets with the leaſt moiſture, in it's paſſage from the furnace to the mould, the watery particles are inſtantly expanded, and throw the burning metal to a conſiderable diſtance.

If a quantity of water be thrown into an iron veſſel, heated red-hot, it will run about the veſſel like quickſilver, but without touching the bottom or ſides, being converted into vapour, which prevents it's coming in contact with the veſſel.

The *eolipile*, or wind-ball, is an inſtrument which exhibits in a pleaſing manner the generation and force of ſteam.

It has a long narrow neck, with a ſmall aperture, through which the ſteam ruſhes with great violence in the form of a factitious wind, which will blow and brighten a fire, put out a candle, and feel like a ſtrong blaſt when received upon the hand.

It is ſometimes placed on a ſmall carriage, (*fig.* 5, *pl.* 5,) a cork is thruſt into the extremity of the pipe; when the vapour has acquired ſufficient ſtrength to force out the cork, it ruſhes out violently one way, while the ball and carriage are carried the contrary way.

The ſteam of boiling water is applied as a mechanical force to the ſteam engine, of whoſe wonderful effects no one can be entirely ignorant.

One of theſe engines was repairing at Chelſea, and as the workmen were buſy about it to diſcover the defect, the barrel burſt on a ſudden, and a cloud of ſteam ruſhing out of the fracture, ſtruck one of the workmen, and killed him in an inſtant, like a blaſt of lightning; his companions haſtened to his aſſiſtance, but when they endeavoured to take off his cloaths, the fleſh came off with them from the bones. A further account of this engine will be given in the proceſs of theſe lectures.

The force of the vapours of ſpirit of wine has occaſioned terrible accidents when the worm has been ſtopped, and the head of the ſtill abſurdly tied down to prevent an exploſion. The vapours of mercury have burſt an iron box, and thoſe of ſal ammoniac, nitrous acid, &c. &c. have all been known to burſt the chemical veſſels which confined them, and with ſuch force as to endanger thoſe who ſtood near them. In ſhort, there is no ſubſtance whatever capable of being reduced into a ſtate of vapour, but what in that ſtate is endowed with an elaſtic force capable of becoming ſuperior to any obſtacle we can throw in it's way.

Evapo-

Evaporation is not confined in it's uſe to a few mechanical engines, but extends to various arts; and is alſo one of the great natural proceſſes by which the vegetable kingdom is ſupplied with the rain neceſſary for it's ſupport.

In chemiſtry, this operation is uſed for ſeparating two ſubſtances from each other, of which one, at leaſt, muſt be fluid, and *whoſe degrees of volatility are very different.* By this means, you may obtain a ſalt, which has been diſſolved in water, in it's concrete form; by heating, the water is combined with fire, and rendered volatile, while the particles of ſalt being heavier and leſs volatile are left behind, and unite into a ſolid ſtate. As during the evaporation the fluid carried off by the fire is entirely loſt, being ſacrificed for the ſake of the fixed ſubſtance with which it was combined, this proceſs is only employed where the fluid is of ſmall value, as water. When the fluid is of more value, the chemiſts have recourſe to *diſtillation,* in which proceſs they preſerve both the fixed ſubſtance and the volatile fluid.

OF EBULLITION AND EVAPORATION.*

Ebullition is an accidental phenomenon, depending on the air contained in liquids; for if this be thoroughly expelled, there will be no ebullition.

You have ſeen that water, in *vacuo,* gives out a great quantity of air in bubbles; theſe are formed in the midſt of the water, increaſe in ſize, and then eſcape. When no more bubbles are produced by this operation, freſh ones may be obtained by *agitating* the water; ſtill more may be diſengaged, if it be *heated.*

The *air* that is engaged in water, is prevented from

* See "Lettres de Mr. de Luc, a M. de la Methrie, publiſhed in the Journal de Phyſique, for 1790, 1791, 1792."

from ſeparating the particles thereof, by the preſſure of the atmoſphere: when this preſſure is removed, thoſe particles of air which are moſt favourably ſituated, begin to move with more liberty, and by their impact to augment the ſpaces in which they are contained, thus giving room for other particles to diſengage themſelves, and form ſmall bubbles; theſe being unequal in ſize, riſe with different velocities; in riſing they often meet and unite, and the ſpace they thus conjointly occupy, is larger than the ſum of the ſeparated ſpaces. This is the cauſe of the firſt phenomenon above mentioned; for by agitating the water, ſpaces are formed void of air, into which, other particles of this fluid diſengaging themſelves from the ſides of the water ſurrounding the empty ſpace, enter; and thus are freſh bubbles of air formed, which would not have been diſengaged without this agitation of the water. Laſtly, by a freſh degree of heat applied to the water, an *expanſible fluid* is introduced therein, that is more ſubtil than air, and is always in motion in the interſtices between the particles of water: by ſeparating theſe, it enables thoſe of air to diſengage themſelves, and thus form more bubbles thereof.

Now if all the air that is contained in any liquid be expelled, that liquid would never boil, neither in vacuo, nor in open air: it would then only evaporate at it's ſurface; the evaporation would indeed be ſlower, but would ſtill be regulated by the ſame laws; and at the *ſame temperature*, the vapours ariſing therefrom, would be *as denſe* as thoſe procured by *ebullition* from liquids not purged of air; for the degree of heat, at which liquids boil, is that where the vapour is capable alone of ſupporting the incumbent preſſure, the vapour being formed in the boſom of the fluid, as ſoon as there is any ſolution of continuity.

This

This reaſoning is confirmed by an experiment made by Mr. Watt, who conveyed ſome water into a barometer tube; the upper part of the tube being formed into a ball, and the air being expelled entirely from the water it contained, the ball was introduced into a veſſel of ſalt water; this was gradually heated; the increaſe of the heat, the march of the water, and the correſponding depreſſion of the mercury, were carefully noted.

The moment the ſteam or vapour, at the top of the inſtrument, had attained the boiling heat, the mercury in the barometer was depreſſed to the level of that in the baſon; the vapour in the inſtrument was therefore then of the ſame denſity, as thoſe which the water therein would have formed if it had boiled; whereas in the preſent experiment, there was *no ebullition*. In proportion as the ſalt-water was more heated, the denſity of the vapours increaſed, and the mercury in the tube fell beneath the level of that in the baſon, till at laſt it was driven entirely out of the tube: there was ſtill, however, no ebullition, though the heat was many degrees above the boiling point.

The depreſſion of the column of mercury, and the correſponding augmentation of heat in the water, coincided, as nearly as could be expected, with the heat aſſumed in other experiments by boiling water, under different degrees of incumbent preſſure.

From this experiment you will naturally infer, firſt, that *ebullition* is only an *accidental* phenomenon, ariſing from the air incloſed in the liquid. Secondly, that with the ſame temperature, ſimilar vapours are detached from water, whether it boils or not. Thirdly, that ebullition does not take place, until the vapour produced in the liquor has acquired a degree of expanſive force ſufficient to raiſe the liquor into bubbles under that preſſure.

It now remains to be explained how vapour is produced in boiling water, and by what means the permanent or constant heat of boiling water is preserved under the same pressure. These phenomena are easily explained by experiment, for this will shew you that vapour is formed in the midst of water, by means of the bubbles of air that are disengaged therein. These bubbles form a solution of continuity into which the vapour enters, and is then expanded and united with fire; hence an evaporation which cools the fluid, and preserves it at a certain temperature.

When the heat is small, the vapour that is formed is so rare, as not to increase the natural effort of the bubbles of air in escaping; but when the heat increases, the steam or vapour that enters the bubbles of air, becomes more dense, and the bubbles are enlarged; the heat being further augmented, the steam contained in the bubbles becomes sufficiently dense to surmount the pressure of the water, it then enlarges the space in which it is contained, and would do this indefinitely, if it were prevented escaping from the surface. M. de Luc put into a retort with a long neck, some water, which was so perfectly freed from air, that no bubbles were disengaged till it had attained the boiling heat; the retort was held in an inclined position, to prevent the steam from escaping by the neck: in this position, one bubble of air disengaged itself, and gave rise to so much steam, as forced out, in one mass, nearly half the water that was contained in the retort; proving that a certain degree of heat is necessary to form steam sufficiently dense to overcome by itself the incumbent pressure.

The bubbles of air, and included steam, are formed, and escape with less heat, when there is less pressure on the surface. Thus, when the pres-

sure

ſure of the atmoſphere is removed, water will boil with a heat not exceeding 95 degrees, that is, 117 degrees below the heat required under the ordinary preſſure of the atmoſphere.

The greater the preſſure, the greater is the degree of heat neceſſary for ebullition, inſomuch that in Papin's digeſter, water acquires a degree of heat equal to that of metals when red-hot.

As ſoon as the ſteam is formed, and eſcapes, the water becomes colder, but ſoon regains it's former heat by freſh ſupplies of fire. The water is cooled by the formation of the vapour within it; thus the quantity of water is diminiſhed, but the heat remains the ſame, being neither increaſed nor diminiſhed; the continued application of fire, by converting a greater portion into vapour, is carried off, ſo that by the evaporation the heat of the boiling point is fixed: this is rendered evident by experiment. Thus Mr. de Luc having expelled the air from ſpirit of wine, found it was capable of ſuſtaining the heat of boiling water; he thence inferred, that by expelling the bubbles of air from water, he ſhould make this fluid ſupport a greater degree of heat than 212 degrees. He made the experiment, and it ſucceeded according to his expectation; when all the air was expelled, no vapour eſcaped, becauſe none of theſe bubbles were formed, and the water at the common preſſure of the atmoſphere, ſuſtained a heat 22 degrees greater than that of the common boiling point: hence alſo it is evident, that ſteam or vapour can only be formed at the free ſurface of fluids.

It was found in the courſe of theſe experiments, that whenever the thermometer had riſen above the boiling point, it immediately fell again to that point; the formation and eſcape of freſh bubbles as it were cooling it down to that heat.

Accurately ſpeaking, therefore, the boiling point

point is only fixed and certain in the ſteam which eſcapes; for the temperature of the water *varies*, being ſometimes above, ſometimes below this point, but always falls, when higher, immediately on the eſcape of ſteam bubbles. The greater the degree of heat that is applied to the water, the more rapid are theſe oſcillations of temperature. The mean temperature, however, remains the ſame, and the only effect of a greater degree of heat, is to produce from the water ſteam-bubbles of a conſtant temperature, in greater number, and with more rapidity.

You may from theſe experiments comprehend why liquids are cooled by evaporation, as well as the nature of evaporation itſelf; the particles of fire being very ſubtil, penetrate and traverſe all bodies continually, in every direction, and undergo therein the various modifications already deſcribed: the permanency of the ſame temperature in any body, and in the air ſurrounding it, will therefore depend on an equilibrium in the ſimultaneous paſſage of the particles of fire from that body into the air, and from the air into that body; and this equilibrium exiſts, wherever fire meets the ſame reſiſtance at coming in and going out, as in ſolid ſubſtances, or in fluids incloſed in ſolids. But the caſe is different with thoſe that have one ſurface free or expoſed, as fluids; for here the fire that enters, does not compenſate for what goes out; the latter being leſs reſiſted than the former, the fire paſſes out more rapidly than it enters, carrying away with it the molecules of water, which it meets with at the ſurface. By this means the fluid is rendered cooler than the ambient air, and the effect is greater in proportion as the molecules of the fluid yield more eaſily to the impreſſion of the particles of fire.

When

When the molecules that have been thus detached from the general maſs, keep at a *certain diſtance* from each other, (which diſtance is regulated by the *temperature,*) they remain united with the particles of fire, and vapour is the reſult, which may be conſidered as an *expanſible fluid*, that obtains from fire it's peculiar properties, while, like other mixtures, it acquires qualities which are not perceivable in the ſeparated ingredients: but if the particles of vapour or ſteam are brought within the above diſtances, they unite and are precipitated.

According to the experiments of Mr. Watt, *boiling ſteam*, when the barometer is at 28 inches, occupies 1800 times more ſpace than the water from which it proceeds. This ſteam is pure, and it's peculiar character is to be ſufficient of itſelf to ſupport the preſſure of the atmoſphere. If you increaſe the ſpace occupied by a given maſs of this ſteam, preſerving the ſame temperature, it dilates, and fills this ſpace, ſeeming to have no other limits of expanſion than the ſpace in which it acts; but if you make it occupy a leſs ſpace, a portion of the ſteam or vapour is deſtroyed, without diminiſhing the denſity of what remains: in this caſe, a portion of the water is precipitated, and a portion of fire diſengaged. The liberation of fire will retard the deſtruction of the remaining ſteam, unleſs it eſcapes through the veſſel in which the ſteam is confined.

The evaporation of a drop of water at the top of a barometer, depreſſed the mercurial column half an inch, when the thermometer was at 57 degrees; the vapour alone, in this inſtance, and with this temperature, ſupported a column of mercury of half an inch. If the column of mercury was raiſed by adding more mercury at bottom, the depreſſion of the barometric column was ſtill

the ſame; a part of the ſteam was deſtroyed, but the reſidue preſerved the ſame denſity till the whole was deſtroyed. This experiment agrees with one of Mr. Nairne's, already mentioned.

By conſidering what has been ſaid, you will find that the *air* has had no concern in the formation of vapour; for in the experiments with boiling water, it is excluded by the ſteam itſelf, and in experiments made in vacuo, it was extracted; yet in both caſes, the ſame phenomena take place as where air is preſent. Meſſrs. de Luc and Sauſſure have further proved this. I ſhall however only relate one more experiment.* A barometer was placed in a veſſel filled with air; the vapour contained in this being abſorbed by proper ſalts, a moiſtened rag was placed therein, and then the veſſel was ſealed. The barometer, when incloſed, was at 27 inches, the thermometer about 64 degrees; the greateſt degree of evaporation raiſed the barometer to 27½ inches, thus coinciding, as nearly as could be expected, with the experiments of Meſſrs. Nairne and Watt.

The phenomena of aqueous vapour are therefore clearly the ſame in open air as in vacuo. The denſity of the vapour is the ſame every where, and at any temperature, provided the particles thereof keep at a certain diſtance from each other. It is equally indifferent whether they be expanded in air or in vacuo, ſo that they are not forced by preſſure within this diſtance. Now the particles of vapour in vacuo are not better ſecured by the ſides of the veſſel from the preſſure of the atmoſphere, than thoſe in open air are by the air itſelf with which they are intermingled, becauſe this air alone already reſiſts this preſſure.

A portion of vapour is at any time deſtroyed by

* Mr. de Sauſſure, Eſſais ſur l' Hygrometrie.

by condensing the air with which it is intermingled. It is indeed a general observation, that humidity is increased by condensing, and diminished by dilating the air. In the same manner in vacuo, at every temperature humidity increases, when the particles of vapour approach within a certain distance, and diminish when they recede further.

Thus does every phenomenon prove that the hypothesis of the *dissolution of water by air, is vague, without any solid foundation, unnecessary for the explanation of evaporation, and involving every branch of philosophy in obscurity.*

OF THE LATENT FIRE IN STEAM OR VAPOUR.

Boiling water, when examined by a thermometer, is not sensibly hotter after boiling several hours than when it began to boil; though to maintain it at that degree of temperature, a brisk fire must be necessarily kept up. What then becomes of this great waste of fire? It is not in the water, nor is it manifested by the steam, for upon examination, this is rarely found to be hotter than boiling water. Dr. Black has proved that this fire is absorbed by the vapour, and that what is so absorbed, is absolutely necessary to the existence of water in the form of an elastic fluid, but which does not increase it's temperature.

The following experiments of Dr. Black will render this subject very plain to you. Having the opportunity of using what is called a kitchen table, or a large thick plate of cast iron; he heated one end thereof red-hot, and placed thereon two flat circular iron vessels, of about four inches diameter, and containing equal quantities of water; the temperature of the water was noted when it was placed on the table, when it began to boil, and when it was nearly boiled away. In four minutes it began

to boil, and ſend forth ſteam, and in the ſpace of 20 minutes, the plate being ſtill of the ſame heat, the water was wholly evaporated. At the beginning of the experiment, the water was at 54 degrees; in 4 minutes, it roſe 158 degrees, or to the boiling point; during each of the ſucceſſive 4 minutes, it received the ſame quantity of heat; that is, in 20 minutes, 5 times 158, or 790 degrees. If the ſteam had gone off with great velocity, we might have ſaid that it was a ſenſible effect of the increaſe of heat; but as neither the heat of the water is increaſed by boiling, nor the ſteam ſent off with any remarkable celerity, we may reaſonably conclude that the fire is abſorbed by the ſteam, and becomes one of it's component parts. The ſurplus heat is neither ſenſible in the water, nor the ſteam; for if you apply a thermometer to the ſteam, you will not find it hotter than the boiling water.

This concluſion is further ſtrengthened by the heat given out by ſteam, on it's being condenſed by cold: this is particularly manifeſt in the condenſation of this fluid, in the proceſs of diſtillation; where, upon examining the refrigeratory, you will find that a much greater quantity of heat is communicated to it, than could poſſibly have been tranſmitted by the heat which was acting ſenſibly before the condenſation: this may be eaſily aſcertained by obſerving the quantity of heat communicated to the water in the refrigeratory of a ſtill, by any given quantity of liquid that comes over. Thus, if the refrigeratory contains 100 pounds of water, and the diſtillation be continued till one pound has come over, ſuppoſing the water in the refrigeratory to have received 8 degrees of heat; if the whole of the quantity thus received, could be thrown into one pound of water, the latter would receive 800 degrees. But that this quantity of heat is received by the refrigeratory, has been proved by experiments;

ments; which consequently shews that water, when converted into vapour, absorbs above 800 degrees of heat.

Dr. Black put some water into a strong phial, having a thermometer in it, and stopped closely with a cork: this he exposed to a sand heat, and brought the thermometer 20 degrees above the boiling point; which was easily effected, as the pressure of the steam on the water, made the fluid capable of greater accessions of heat. He then pulled out the cork, supposing that the water would immediately disappear, by flying out in vapour. This did not happen; for upon taking off the mechanical pressure, a sudden and very tumultuous ebullition ensued, during which a portion of the water was forced out of the phial, together with a quantity of steam; the water in the phial sunk down to 212, almost as soon as the cork was pulled out. Now as the additional heat does not appear in the water, though the minute before it acted sensibly in it, we may conclude that the fire occasioning it is combined with the steam.

Mr. Watt, under the direction of Dr. Black, put a quantity of water into Papin's digester, and raised it to 412 degrees. After confining the steam for a long time in such a pressure, he judged that upon admitting the air, and giving vent to the obstructed steam, the whole mass of water would instantly evaporate; this was not however the case, a quantity of steam flew out with considerable noise, and with such impetuosity, as to rattle several times against the ceiling of the room; yet far the greater part of the water remained, which immediately sunk to 212 degrees; whence it was concluded, that the fire, thus put in action, was absorbed by the steam, by which means the temperature of the water was reduced to the boiling point. In this experiment the water was heated

200 degrees above the boiling point. If the conversion of water depended merely on the quantity of sensible heat, the whole of the water must have been evaporated, whereas a small quantity only went off in vapour.

I have already dwelt a considerable time on this subject; but the importance of it towards a right understanding of the most part of the phenomena in nature, will be a sufficient excuse, and will, I am sure, encourage you to hear with attention an account of further experiments on this interesting branch of philosophy; the more so as you are sensible that natural philosophy consists in exploring, by experiment, the phenomena resulting from the mutual action of different bodies on each other; as these phenomena are innumerable, experiments must be so also; for no arithmetic can reckon up the various ways in which terrestrial bodies may, by natural and artificial means, be brought to operate on each other.

If eight pounds of iron filings, at 212 degrees, be mixed with a pound of water at 32 degrees, the temperature of the mixture will be 122 degrees nearly; the iron will be cooled 90 degrees, and the water heated 90 degrees.

But if eight pounds of iron filings, at 300 degrees, be mixed with a pound of water at 212 degrees, the temperature of the mixture will be 212 degrees, and a part of the water will be sensibly converted into vapour: if a sensible thermometer be so suspended as to be in contact with the vapour thus produced, it will be found also at the temperature of 212 degrees. In this experiment, you see that 88 degrees of fire, separated from the iron, raised a portion of the water into the form of vapour, but did not increase the temperature thereof; the vapour that escaped was also at the boiling point. As the fire separated from the iron is not

 communi-

communicated to the water, it muſt neceſſarily be abſorbed by the vapour.

From theſe experiments it evidently appears, that fire may ſo exiſt in bodies, as not to diſcover itſelf in any other way than by it's action on the minute parts of the body; and that this action may be ſuddenly changed ſo as to be no longer directed on the particles of the ſubſtance itſelf, but upon external objects, in which caſe we perceive it's action by the ſenſe of feeling, or diſcover it by the thermometer. It alſo appears from theſe experiments, that water, in it's fluid ſtate, hath as much fire combined with it as it can contain, and yet remain in that ſtate; in other words, the elementary fire within it *expands or ſeparates it's parts from each other as much as is conſiſtent with it's conſtitution as water.*

If any more is added, it cannot be abſorbed or combined, or direct it's force on the particles of the water, without raiſing them in vapour: part, therefore, of this additional expanſive power will be employed in the formation of vapour, and the reſt will be communicated to the neighbouring ſubſtances.

It alſo appears as evident as experiment can make it, that fire is the cauſe of fluidity: now as fire, when producing heat, expands bodies in every direction, we may conclude that it acts as from a center towards a circumference, and that cold is a diminution of this action, or a condenſation from a circumference towards a center; conſequently when the expanſive action of fire is confined within the ſurface of the body, it cannot affect the thermometer, and may be called, in this ſenſe, *latent fire.* When the expanſive action is transferred from the internal parts of the ſubſtance to the ſurface, it then affects the thermometer, though congealing

or freezing, the latent fire being then rendered ſenſible.

A certain degree of expanſive power exiſts in all bodies; this has been termed the ſpecific fire of the body. When the expanſive action of fire, within any ſubſtance, becomes greater than is conſiſtent with the coheſion of that ſubſtance, it is diſſipated or reſolved into vapour: this, however, may be effected in ſuch a way, that this fire may ſtill act upon the ſeparated parts, without exerting any of it's force upon external ſubſtances; and conſequently vapour will continue to exiſt as ſuch in a degree of heat much below that at which it was produced. When this latent fire is transferred to other bodies, the vapour ceaſes to be vapour, is condenſed, and in moſt caſes returns to it's original ſtate.

Every ſubſtance has a proper proportion of fire combined with it; conſequently whenever it is decompoſed, or new combinations take place, there will be either an equal, a ſmaller, or a greater quantity of fire employed: if an equal quantity is uſed, there will be no fire diſengaged, nor any abſorbed; in other words, no portion of liberated fire will be combined, nor will any that was combined be ſet at liberty. But in the ſecond caſe, where leſs fire enters into the new combination, than was in the preceding one, a portion of the fire that was combined, before the decompoſition, will be ſet at liberty, and will remain diſengaged; after the recompoſition, it will re-aſſume it's properties, and will produce the effect we call heat, and will diſſipate itſelf inſenſibly among the ſurrounding bodies. In the third caſe, when more fire enters into the new combination than was there before, the fire from the ſurrounding bodies will be abſorbed, and paſs from the ſtate of free, to combined fire; as the ſurrounding bodies are thus

thus deprived of a portion of their free fire, they will therefore become colder, and continue ſo till the equilibrium is reſtored by fire from other bodies.

You have thus a ſenſible and clear criterion, by which you may diſtinguiſh when fire is diſengaged or abſorbed in any combination whatſoever; in the firſt caſe the ſurrounding bodies will be heated, in the ſecond cooled.

As whenever fire is abſorbed by entering into combination, cold is produced, we may infer that whenever cold is perceived, a quantity of liberated fire is become combined, or that there has been an abſorption of fire by the combination.

Now as in the formation of vapours, cold is always produced, we may be aſſured that fire is abſorbed when vapours are formed, or that vapours reſult from the combination of fire with a fluid reduced to a vaporous ſtate.

As an objection may be made to the foregoing theory, it will be neceſſary to conſider it before we proceed any further. If no aeriform fluid can be formed, ſays the objector, without a portion of fire paſſing into, and being combined with it, cold ought always to be produced in the formation of every aeriform fluid; whereas in the combination of calcareous earths, and effervеſcing alkalies with acids, inſtead of cold a ſenſible heat is generally obſerved during the formation of the fixed air.

This phenomenon, far from invalidating the former theory, only proves, that in theſe combinations, more fire is diſengaged than is neceſſary for forming the fixed air, which is clearly proved by ſhewing that the quantity of heat may be increaſed or diminiſhed at pleaſure, according as the quantity of fixed air in the alkali is increaſed or diminiſhed: volatile alkali alone, fully ſaturated with fixed air, produces cold inſtead of heat, when

the air is disengaged therefrom. Mr. Lavoisier has made a great many very satisfactory experiments on this head.

OF THE COLD PRODUCED BY EVAPORATION.

You have seen that evaporation, though produced by fire, is a cause of cold; it is indeed the principal means used in the processes of nature for regulating the temperature of the earth. To understand it's operations, and have a proper idea of this process, I shall shew you some very curious experiments, and relate others; pointing out, at the same time, such applications of this general phenomenon, as cannot fail to render it highly interesting.

Take this thermometer filled with water, and plunge the ball in water, letting it remain there till it is of the same temperature; then take it out, and agitate it in the air, the water on the surface of the ball evaporates, and you see that in the thermometer falls: by repeating this operation a number of times, you may even freeze the water in the ball.

If you wrap the ball of a thermometer with fine linen, and keep this moist by sprinkling it with ether, and then agitate or move it briskly in the air, the thermometer will descend to 0°. Spirits of wine, ether, and many other fluids, produce a greater degree of cold than water; probably in consequence of their being more evaporable. The degree of cold produced by evaporation, depends probably on the velocity with which it is accomplished. Now the promptitude in evaporation of water of a definite temperature, depends partly on the prevailing degree of heat, partly on the current of air acting on the thermometer, and partly on the dryness and moisture of the air.

From the experiments of M. Richmann, we find,

find, 1. That a thermometer, taken out of water, and expoſed to the air, always deſcends, even when it's temperature is equal or ſuperior to that of the water. 2. That it afterwards riſes till it has attained the temperature of the atmoſphere. 3. That the time of deſcending is leſs than that which it employs to riſe again. 4. That when the thermometer, withdrawn from the water, has ariſen to the common temperature, it's bulb is dry; but that it continues wet during the whole time of it's ſtanding beneath this common temperature.

The experiments of Dr. Cullen ſhew us, 1. That a thermometer, ſuſpended in the receiver of an air-pump, deſcends two or three degrees during exhauſtion, and afterwards riſes to the temperature in the vacuum of air. 2. A thermometer plunged in alcohol in the receiver of the air-pump, always deſcends; and that lower in proportion as the bubbles are ſtronger which iſſue from the alcohol. If it be taken out of the liquor, and ſuſpended wet in the receiver, it falls 8 or 10 degrees, while the air is pumping out. Dr. Cullen placed ſome very volatile liquors under the receiver of an air-pump; one of theſe was ether; it was contained in a glaſs, in which there was alſo ſome water; when the air was extracted, the ether began to boil, and to be converted into vapour, till it became ſo cold under the receiver, that it froze the water contained in the veſſel, though the temperature of the room was about 50 degrees.

You may freeze water at any time, by the evaporation of ether; for this purpoſe you ſhould be furniſhed with a thin glaſs tube, to hold the water like this in my hand, and a bottle of ether with a capillary tube fitted to the neck: I ſhall keep the outſide of the glaſs tube wet with the ether, and the ſpeedy evaporation of this very volatile fluid will ſoon convert the water into ice, and this it

will do even before a fire, or in the midſt of ſummer.

We may, therefore, lay down the following circumſtances, as the moſt general conſequences that ariſe from the experiments made on evaporation: 1. That if a thermometer be plunged into any evaporable fluid, and immediately taken out again, it will deſcend ſeveral degrees while the bulb is drying; as ſoon as the fluid is all evaporated, it will begin to riſe, and continue to do ſo until it has acquired the temperature of the ſurrounding air. 2. That the cold produced is greater in proportion as the fluid is more evaporable; the bulb of a thermometer, moiſtened with water, does not deſcend ſo rapidly as one wetted with ſpirit of wine; and this leſs ſo than one moiſtened with ether. 3. If the evaporation is accelerated by any means, excepting by heat, there will be a proportionable augmentation of cold, ſo that evaporation is not only productive of cold, but the degree of cold depends alſo on the rapidity of the evaporation. 4. That by continuing to wet the bulb as faſt as it dries, the cold continues to be increaſed, becauſe the producing cauſe continues it's action.

Sailors, in calm weather, often hold up a wet finger in the air, and if one ſide of it becomes, in drying, colder than another, they expect wind from that quarter. This cuſtom is not without it's foundation, for an almoſt inſenſible motion in the air, will evaporate the water from one ſide of the finger ſooner than from another, and thus produce cold. By a ſimilar experiment, you may experience the cold produced by evaporation; wet your finger by putting it in your mouth, and then hold it up in the air, and you will find it grow cold as the moiſture evaporates.

Though this property of producing cold by evaporation has been but lately obſerved by chemiſts,

miſts, yet it has been long employed by thoſe who knew nothing of the operation. It has been obſerved at Aleppo, in Syria, that the water in their jars is always the cooleſt when the weather is the warmeſt, and the power of the ſun exceſſive. The heats in that part of the world are ſometimes almoſt intolerable, and at that time the evaporation from the outſide of the jars, which are made of porous earth, is very copious, and the cold within is in proportion to the quantity of water evaporated from without. Kæmpfer relates, that the winds are ſo ſcorching on the borders of the Perſian gulph, that travellers are ſuddenly ſuffocated, unleſs they cover their heads with a wet cloth; if this be too wet, they immediately feel an intolerable cold, which would become fatal if the moiſture was not ſpeedily diſſipated by the heat.

Mr. Swinburne ſays, they have a kind of earthen jar in ſome parts of Spain, called *buxaros*, which are only half baked, the earth of which is ſo porous, that the outſide is kept moiſt by the water that filters through it, and though placed in the ſun, the water in the pots remains *as cold as ice*. The blacks at Semigambia have a ſimilar method of cooling water; they fill tanned leather bags with it, and hang them up in the ſun; the water oozes more or leſs through the leather, ſo as to keep the outward ſurface wet, which, by it's quick and continued evaporation, cools the water.

The manner of making ice in the Eaſt Indies depends on the ſame principle, that of producing cold by evaporation. The *ice makers* dig pits about 30 feet ſquare, and 2 deep, on large open plains: they ſtrew the bottoms of theſe pits, to the thickneſs of about 8 inches or a foot, with ſugar canes, or with the dried ſtems of India corn: upon this bed they place a number of unglazed pans, which are made of ſo porous an earth, that the water pene-

 trates

trates through their whole ſubſtance: theſe pans, which are about a quarter of an inch thick, and a quarter deep, are filled towards the duſk of the evening, in the winter ſeaſon, with water which has been boiled, and then left in that ſituation till morning, when more or leſs ice is found in them according to the temperature of the air; there being more formed in *dry* and *warm* weather, than in that which is cloudy, though it may be colder to the human body. Every thing in this proceſs is calculated to produce cold by evaporation; the beds, on which the pans are placed, ſuffer the air to have a free paſſage to their bottoms, and the pans, in conſtantly oozing out water to their external ſurface, will be cooled by the evaporation.

Cellars and ſubterraneous vaults, at a certain depth, are commonly dry in winter, and very wet in ſummer. In ſummer, the air is hotter than the interior of the earth; and fire which always tends to an equilibrium, deſcends into the upper ſtrata of the earth, with the water it bears: it depoſits this water in theſe ſtrata ſucceſſively, in proportion as it penetrates and finds them colder; thus they become loaded with humidity to a certain depth, and retain it, until by a change in the atmoſphere, which the cold brings with it, the fire returns from the earth to the air, and gradually carries away with it the water it had depoſited during the ſummer.

That fire effects evaporation with great energy, when not reſtrained by the air, is evident from the following fact: in the upper part of barometers, well purified from air, and expoſed to conſiderable changes of temperature, as for example, at a window upon which the ſun ſhines, you will ſee the mercury raiſed, and depoſited in little drops on the empty part of the tube: theſe drops gradually increaſe, and at length fall back by their weight. This is a real diſtillation, which takes place in the

ordinary

ordinary temperature of the atmoſphere; the fire, although in this inſtance of very inconſiderable denſity, raiſes the mercury, which is nearly 14 times heavier than water, and carries it, at leaſt, to the height of 2 inches, and depoſits it on the coldeſt ſide of the glaſs, where it has the greateſt tendency to traverſe it. This is one among many phenomena which ſhews that evaporation does not ariſe from any diſſolving power in the air; for in this caſe the air was excluded, but is to be aſcribed ſolely to the agency of fire.

It is on theſe principles that the air over a wood or foreſt, is made colder by the evaporation from trees and ſhrubs. Thus plants are kept in a more moderate air, and ſecured from the burning heat of the ſun, by the vapour perſpired from their own leaves; and hence the ſhade formed by vegetable bodies, is more effectual to cool us, as well as more agreeable in itſelf, than the ſhade of rocks and buildings.

When the human body is moſt heated, the vapour paſſes off at the ſkin by perſpiration. If the pores are cloſed, what ſhould evaporate is reverberated, and works inwardly upon the body, like the ſteam confined in Papin's digeſter, and the blood riſes far above it's due heat into a fever, as water in that veſſel riſes far above the heat of boiling: thus numbers of labouring people ſupport themſelves in the height of ſummer, by virtue of a copious perſpiration, which they repleniſh by drinking plentifully; the liquor is carried off by perſpiration, and the body is kept cool by the fire which the evaporation of the ſweat carries off. The workmen employed in glaſs houſes, founderies, &c. often live in a medium hotter than their bodies, the natural temperature of which is equalized and moderated by perſpiration.

Thus has Providence contrived to render the heat

heat of the torrid zone leſs inſupportable to the inhabitants. An intenſe heat bathes the body in ſweat; but the ſweat being evaporated, carries with it a large portion of the fire by which it was occaſioned, and thus cools the body. If evaporation be increaſed by agitation of the air, the refrigeration is greater; hence the uſe of fans and ventilators, which, though intended to give motion to warm air, cool likewiſe, by facilitating and favouring evaporation. Warm and dry air is beſt ſuited to form a refreſhing current, becauſe it is more calculated to carry off humidity: from hence alſo we may ſee the neceſſity of frequently renewing the current of air to preſerve the coolneſs of our apartments.

Theſe principles, ſays M. Chaptal, have alſo a nearer relation to medicine than is generally ſuppoſed. Moſt fevers end in perſpiration, which, beſide the advantage of expelling the morbific matter, poſſeſſes that of carrying off fire, and thus reſtoring the body to it's common temperature. The phyſician, who is deſirous of moderating the exceſs of heat in the body of a patient, ought to maintain the air in that diſpoſition which is moſt ſuitable to his views.

May not theſe principles account for the effect of ſome medicines? The uſe of volatile alkali is univerſally acknowledged in burns, the tooth-ache, &c. May not theſe effects be attributed to the volatility of this ſubſtance, which by combining with, and carrying off fire, leaves an impreſſion of cold? May not alſo the effect of ether, which is a ſovereign remedy for the cholic, depend on the ſame principles?

Moſt of the phenomena of evaporation are conveniently and elegantly ſeen in theſe glaſs tubes, (*fig.* 7, *plate* 5,) with hollow balls at their extremities; the balls freed from air, and half filled with

with water or ſpirit of wine. If you lay hold of each ball at the ſame time, you will ſee no ebullition in either; but if you only lay hold of one, it will be warmed by the hand, while the other remains cold, and the water will immediately fly from the one which is warmed, and riſe into the other which remains of the ſame temperature. When the water is all gone into the ball furtheſt from your hand, you ſee it begins to boil, and this ebullition will laſt a long time, provided you keep your hand on the empty ball.

Theſe phenomena are eaſily explained from what has been already ſhewn you; the fire paſſing from the hand into the glaſs, converts into vapour the thin coating of moiſture which lines the ball; but when the balls are equally warmed, the preſſure being equal on both ſides, the vapour cannot act and develope it's properties. When one only of the balls is heated, the vapour is formed in great abundance, and forces the water into the other; the fire at the ſame time paſſing through, occaſions the ebullition in the other, by forcing up the vapour it raiſes through the water into the other ball; the vapour ariſing from this, parts again with it's fire againſt the cooler ſides of the glaſs. You may be eaſily convinced, that this ebullition is occaſioned by the vapour raiſed by the heat of the hand, from the humidity which coats the ball; for if you graſp this ball in the hand, keeping it in ſuch a poſition that the water cannot enter it again, the ſides thereof will ſoon become quite dry, and the ebullition will entirely ceaſe: but if you moiſten the inſide of the ball with a drop of water, the ebullition will immediately commence.

Another remarkable phenomenon that this little inſtrument preſents to your attention, and which you muſt already have obſerved, is this; that as long as there is any moiſture in the inſide of the

ball

ball to be changed into vapour, the hand feels a cool ſenſation, although it is cloſely graſped thereby, all the fire that proceeds from the hand being combined with the water, to change it into an elaſtic vapour; but the inſtant the ebullition and evaporation ceaſes, the ball becomes warm.

You may demonſtrate with this inſtrument, in another manner, the cold produced by evaporation: for this purpoſe, hold the middle of the tube in the hand, and in an horizontal poſition, the bubbles being uppermoſt, and containing nearly the ſame quantity of water in each. Now waſh one of them two or three times with a hair pencil that has been dipt in ſpirit of wine or ether, and you will ſee all the water paſs into the moiſtened ball, and begin to boil with force; the reaſon of this phenomenon is very plain, the evaporation from the moiſtened ball has carried off part of the fire contained therein; the vapour in this ball loſing it's fire, and being thereby condenſed, does not act againſt that in the other ball, which preſſes the water, and this occaſions the ebullition.

Here is one of theſe inſtruments, (*fig.* 9, *pl.* 5,) fixed upon an axis with the balls upwards, and a board facing them, in which are two holes, ſo placed as to correſpond with either of the balls when it preponderates: place this before the fire, and the vapour from the water in the lower ball will ſoon force out the liquor in this ball, which aſcending into the other, it becomes the heavieſt, and falls down, and being then oppoſite to the hole facing the fire, a portion of the water therein will be rarified, and force the reſt into the other ball which will again deſcend. It is not improbable, ſays Dr. Franklin, that this power of eaſily moving water from one end to the other of a moveable beam, by a ſmall degree of heat, may hereafter be applied advantageouſly to ſome mechanical purpoſes.

Of

Of Spontaneous Evaporation.

The experiments we have made with our ſmall glaſs apparatus, have prepared us for the conſideration of that ſpecies of vapour which riſes with very little heat, and is in general imperceptible: as this evaporation is perfectly quiet, it evidently proceeds from the ſurface only, and is therefore proportionably greater as the ſurface is enlarged. Equal quantities of water being put into two unequal veſſels, the one broad and ſhallow, the other narrow and deep, the former will exhale much more abundantly than the latter.

It has long been thought that the air diſſolves the water, and thus occaſions this evaporation; but this opinion does not ſeem well founded; the contrary has indeed been already proved. There certainly is a conſtant ſlow evaporation from fluids expoſed to free air; yet it is evident that fire is the principal agent concerned in this evaporation, from the refrigeration which always accompanies the proceſs. To ſuppoſe that air acts upon water as a menſtruum or ſolvent, brings us only to the ſame concluſion; for how do ſolvents act? Not by any occult virtue in the ſolvents themſelves, nor in the matter they act upon; but on ſomething adventitious to both.

Water diſſolves ſalt as a menſtruum; but only under certain conditions, which proves that the power is not altogether in the water, but in ſomething elſe. Hot water will receive and retain many more of the ſaline particles, than water which is cold and lukewarm; and when with a certain degree of cold water becomes fixed into ice, it loſes it's mobility, and can diſſolve nothing.

Further, as all motion is in the direction of it's cauſe, whereſoever you ſee a body move in any direction,

direction, you may safely affirm, that there is a cause acting in that direction. But if you suppose air to act as a menstruum on water, by the power of attraction, you must suppose it to act downwards, and draw water upwards, which is contrary to the laws of motion; all motion being in the direction of the *moving cause:* you must therefore resolve the ascent of vapour into *impulse,* into the agency of a cause which diffuses itself every way, and acts in all directions. When vapour rises from the surface of an heated fluid, all is consistent and rational; the fire goes off the same way, and so the cause and effect are in one direction; and therefore if we would be consistent, we must reduce other cases to this, and argue that all gentle and slower operations are on the same principle as where the operation is quicker, as the cause is more violent.

Fire, which is the great cause of solution, is also the cause of *spontaneous evaporation.* The earth and sea perspire, when they are heated like the human body; and no one ever yet supposed that perspiration was owing to the air that surrounds the skin of an animal; although this vapour, like that of the rivers and sea, goes off into the atmosphere, it is not the *air without,* but the *fire within,* that is the cause; the air only receives it, and may do this more or less, according to the state it is in with respect to cold or heat, rarity or density. If this reasoning wanted further confirmation, you may have recourse to the experiments you have already made, which prove that evaporation is produced in greater quantities in vacuo than in open air; whereas on the opinion of solution, no such effect should take place, as the solvend cannot be dissolved without the presence of the menstruum.

Spontaneous evaporation is much assisted by mechanical motion. The ground, when wetted with rain, dries very fast, if there is a brisk wind, by

by which the parts of the water are abraded and carried into the atmosphere: as water, when agitated, will take up the parts of earth or mud from the bottom, and keep them asunder as long as the agitation continues, though the earth would have remained at the bottom as a sediment, and the water would have been transparent, if it had been undisturbed.

There are many operations carrying on in the order of Providence, which, though they escape the common observation of our senses, excite our astonishment, when once discovered. One instance of this kind we have in the water which is raised into the atmosphere from the surface of the earth. Would you have conjectured that an acre of ground, after having been parched by the heat of the sun in summer, dispersed into the air above 1600 gallons of water in the space of twelve of the hottest hours of the day? The experiments from which this fact was deduced by *Dr. Watson, Bishop of Landaff*, are so easy, that you may easily satisfy yourself with the truth of the conclusion. He put a large drinking glass with it's mouth downwards upon a grass plat which was mowed close, at a time when there had been no rain for above a month, and the grass was become brown; in less than two minutes the inside of the glass was clouded with vapour, in half an hour drops of water began to trickle down it's inside in various places. The experiment was repeated several times with the same success.

To estimate the quantity thus raised in any certain portion of time, the bishop measured the area of the mouth of the glass, and found it to be 20 square inches: there are 1296 square inches in a square yard, and 4840 square yards in an acre; therefore by measuring the quantity of vapour raised from 20 square inches of ground in one quarter of an

 hour,

hour, it will be easy to calculate the quantity which would be raised with the same degree of heat, from an acre of ground in 12 hours. When the glass had stood on the grass plat one quarter of an hour, and had collected a quantity of vapour, he wiped the inside with a piece of muslin, whose weight had been previously ascertained; as soon as the glass was wiped dry, the muslin was weighed again, the increase of weight shewed the quantity of vapour which had been collected; the medium increase of weight from several experiments made in the same day between 12 and 3 o'clock, was 6 grains collected in one quarter of an hour, from 20 square inches of earth. If you take the trouble of making the calculations, you will find that above 1600 gallons (reckoning 8 pints to the gallon, and estimating the weight of a pint of water at one pound avoirdupoize, or 7000 grains troy weight,) would be raised at the rate here mentioned from an acre of ground in 12 hours. Repeating the experiment after a thunder shower, he found that an acre parted with above 1900 gallons of water in 12 hours.

This evaporation is carried not only from the ground itself, but from the leaves of trees, grass, &c. with which it is covered; and great part of the water thus raised, falls down again in dew in the night-time, being absorbed by the same vegetables which yielded it before. Thus the earth is not so soon exhausted of moisture, even for a little way below the surface of the earth, as we might be apt to imagine, from the quantities raised by evaporation. Perhaps also, one great use of marles and manures, may be to render the soil on which they are put, less liable to be deprived of it's moisture in summer. There are many sandy and lime-stone soils which are covered all over with flints or lime-stone pebbles; the crop of corn would probably

probably be leſs, if theſe ſtones were removed; for they are ſerviceable, not only in ſheltering the germs of the plant, but in impeding the eſcape of moiſture from the earth.

Whether a merely moiſt ſoil be unwholeſome, may be much doubted; but that moiſture ariſing from earth or water in a ſtate of putrifaction, is ſo, cannot well be doubted. The overflowing of the Nile puts a ſtop to the plague, probably as it puts a ſtop to the putrifaction of the canals at Great Cairo and other places. Agues and putrid fevers are much more frequent in the fens of *Cambridgeſhire* and *Lincolnſhire* in very dry than in wet years. The *Iriſh*, who come annually to reap the harveſt in theſe fens, are ſo ſenſible of the difference, that when there have been three or four dry ſeaſons together, they enter upon their taſk with reluctance, apprehending what they call the *fen-ſhake*. In 1748, the States of Holland laid the country around Breda under water, to be kept up till the winter, to ſtop a ſickneſs, which had ariſen from the moiſt and putrid exhalations of half-drained grounds.

Upon the theory of ſpontaneous evaporation, many of the common appearances in nature are explained. When you bring a cold veſſel into a warm room, particularly where many people are aſſembled, the outſide will ſoon be covered with a ſort of dew: the reaſon is obvious; the air is filled with vapour, particularly from the lungs; this meeting with the cold veſſel is condenſed, the fire enters to reſtore the equilibrium, and quitting the vapour, this is depoſited in it's fluid ſtate on the outſide of the veſſel. During a courſe of cold weather, the ſtone pavements, the walls of a houſe, and other ſolid objects, are deprived of a part of their fire; on a change of weather, when the warmer air enters the houſe, the fire enters theſe bodies to reduce them to the general temperature,

 and

and depoſits the vapour on the ſurface in it's paſſage. In a froſty night, when the air abroad is colder than the air within, the dampneſs of the internal air ſettles on the glaſs panes of the windows, and is frozen within-ſide in beautiful forms.

OF THE ABSORPTION OF FIRE BY COLOURED SUBSTANCES.

You have ſeen that the various methods made uſe of for the admeaſurement of heat, are founded on the general principle, that different ſubſtances abſorb fire in greater or leſs quantities; this will be further illuſtrated by a few plain facts, which I am now going to relate to you. In the reception of heat from the rays of the ſun, much depends on the ſurface of bodies; thoſe that reflect much light imbibe heat ſlowly, ſo that the ſame body, when poliſhed, is heated with more difficulty than when it is rough: but the greateſt difference ariſes from the colour of the ſurface; this was firſt pointed out by Boyle, and ſince by Dr. Franklin.

It is the property of white bodies to reflect light, and of black ones to admit or abſorb it; therefore black bodies grow hot in the ſame ſituation where white ones are but little affected. To illuſtrate this, *Dr. Franklin* placed on the ſurface of ſnow ſeveral pieces of cloth of the ſame texture, but of different colours, ſo as to be expoſed to the rays of the ſun; in a few hours the black cloth was buried in the ſnow, while the white remained on the furface.

M. de Sauſſure relates, that the peaſants of the mountains of Switzerland are careful to ſpread a black earth over the ſurface of grounds covered with ſnow, when they are deſirous of melting it to ſow the ſeed.

White

White cloaths, whatever be their ſubſtance, are always cooler, when expoſed to the ſun, than black, of the ſame texture. If the wall at the back of a fruit tree be painted partly white and partly black, the fruit on the black part will be forwarder than the other. *Denſe* bodies have alſo an advantage over rare ones; *lead*, painted black, will receive more fire from the ſun, and be hotter than *wood* of the ſame colour. The difference occaſioned by colours of the ſame ſubſtance is greater than would be expected, as you may eaſily aſcertain, by obſerving the height to which a thermometer, with a blackened ball, will riſe, when compared with one whoſe ball is of clear glaſs; when theſe are expoſed to the ſun, the difference will ſometimes amount to 10 degrees, varying with the brightneſs of the light, and clearneſs of the air; when expoſed to ſtrong day-light, the thermometer with the blackened ball is always ſomewhat higher than the other. Both thermometers being placed at about two inches from a lamp, the coloured thermometer was always ſomewhat higher than the uncoloured one; but at 14 or 15 inches diſtance, the difference vaniſhed.

The obſervation that different colours acquire different degrees of heat, has, by ſome French writers, been attributed to Dr. Franklin; whatever merit there may be in the diſcovery, it will appear from the following extract, that Dr. Franklin has ſaid nothing on the ſubject, but what had been previouſly mentioned by the great *Boerhaave*. Indeed every one who wiſhes to comprehend the wonders that preſent themſelves in a natural hiſtory of fire, ſhould read Boerhaave's incomparable diſcourſe thereon. In Boerhaave alſo, we find a man who was ſo far from being made impious by philoſophy, or vain by knowledge, or by virtue, that

he aſcribed all his abilities to the bounty, and all his virtues to the goodneſs of God.

"If fire," ſays he, "be determined by the ſun on the blackeſt known bodies, it's heat will be long retained therein; hence ſuch bodies are the ſooneſt, and the moſt heated by the ſame fire, as alſo the quickeſt dried, after having been moiſtened by water; they alſo burn much the readieſt. Let a piece of cloth be hung in the air, expoſed to the ſun, one part of it dyed black, another part white, another ſcarlet, &c. the black part will always be found to be the hotteſt, and to be ſo ſooner than the others; the white acquires heat ſloweſt, the reſt in proportion as their colour is brighter or weaker.

"This was well known to the nations who inhabit the hotter climates, where the outer garments, if of a white colour, are found to preſerve the body beſt from the heat of the ſun, while black ones increaſe that heat. It has alſo been obſerved by the makers of woollen cloth, that if at the ſame time and place they hang out two wet pieces, the one black, the other white, the former will ſmoak and dry quickly, but the latter retains it's water longeſt; and that cloths of other colour dry ſo much the ſlower as their colours are lighter.

"It has alſo been long ago obſerved, that all black bodies are ſooner kindled and ſet on flame by the ſame fire, than thoſe of any other colour. The duſt of white touch-wood will hardly take fire, whereas if ſome be placed on a black coal, and a ſpark ſtruck upon it, the duſt thereof will readily receive and keep up the fire. If a piece of white paper be laid in the focus of a burning glaſs, it will be a long time before it takes fire; and as ſoon as kindled, quits it's whiteneſs, turns brown, and then black; immediately after which it burſts out

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in flame: whereas if a piece of black paper be laid on the ſame focus, it immediately takes fire.

"A black ſoil burns the feet, but ſpares the eyes; walking on a white one ſcarce warms the feet, but is troubleſome to the eyes: the ſame may be obſerved with regard to paintings and hangings. Hence you may take a hint for making proper ſhades to keep heat from the body, and the blaze of light from the eyes. Thus, covers for the head white on the outſide, but the lower brim black, afford a great relief to the head in a ſcorching ſeaſon."

By conſidering theſe facts, we may account for ſome phenomena that have been long noticed, namely, that the higheſt parts of the air are the coldeſt, and the contrary. On the Alps, Pyreneans, &c. the ice and ſnow riſe higher than the clouds, and ſeem to increaſe: this Dr. Black accounts for in the following manner. Though the ſun appears to be the ſource of heat in the globe, yet it's rays do not heat a body that is perfectly tranſparent; when the body is not perfectly tranſparent, and reflects ſome few of the rays, it is ſomewhat heated, though not in compariſon with an opake body; hence black bodies are ſooneſt heated. If a burning glaſs be ſo placed that the focus falls a little below the ſurface of ſome tranſparent water, the water will not be heated: if you plunge a ſtick into this part of the water, the interior parts will be immediately burnt to a coal, the ſurrounding water preſerving the exterior parts. As the rays of light do not heat tranſparent bodies, they have little effect upon the air; the upper part is more tranſparent than the lower, and the lower parts receive almoſt all their heat in a ſecondary manner by reflection. The atmoſphere may be conſidered as conſiſting of very eccentric layers, the loweſt being the denſeſt; they are rarified a little by heat,

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but are compreſſed by the ſuperior ſtrata. I have before obſerved to you, that a hot body placed in vacuo loſes it's heat; the heat of the lower ſtrata is therefore preſerved by the compreſſion of the ſuperior air on the ſurface of the earth where it is intended to act. The coldneſs of the air condenſes the vapours, and cauſes them to fall in ſhowers, upon which the life of vegetables depends. You may hence perceive the uſe of planting the higher parts of a country: as green-houſes, made of glaſs, receive the heat tranſmitted through it, but confine the air in them when heated, ſo theſe plantations prevent the lower moiſt ſtrata being removed, which, when the land is naked and expoſed, are quickly carried away by ſcorching winds.

OF IGNITION.

Bodies in certain degrees of heat appear luminous. A body which is thus rendered luminous, is ſaid to be ignited, and the effect itſelf is called ignition.

The nature of the connection between light and heat we have not yet been able to aſcertain; they are both effects of fire, effects, however, that may be ſeparated; but that there is a connection is manifeſt; the ſtronger the light is, the more intenſe we find the heat, and the weaker the light, the fainter you will find the heat.

The degree of heat in which bodies begin to be luminous, or emit light, is thought to be fixed, not only in reſpect to the ſame body, and at all times, but alſo to different bodies. Put into a crucible a number of different ſubſtances that are capable of bearing a red heat, apply heat properly thereto, and you will find that they all begin to be luminous at the ſame time, and as the heat is increaſed they aſſume a deeper or a fainter colour.

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We have indeed no ſtandard for eſtimating the beginning or loweſt degrees of ignition: the only ſtandard is the organ of ſight, which is differently affected as the circumſtances differ; beſides, we cannot be ſure that we perceive the loweſt degrees of light, for we know that other animals ſee objects with ſuch light as appears perfect darkneſs to us. A perſon coming out of a room full of candles into a place moderately lighted, will think it quite dark; on the other hand, one who is long confined to a dark room, will find his eyes dazzled by a weak light.

That ignition is a univerſal effect of fire, may, I think, be fairly concluded, from the variety of bodies in which it is found to take place; for although many ſubſtances have never been rendered luminous, yet it would be unphiloſophical to ſay that they are incapable of ignition, becauſe the degree of fire neceſſary to ignite them is more than ſufficient to convert them into elaſtic vapour. Even water, which in it's natural ſtate ſeems very little capable of enduring ſo great a degree of heat, may, with the aſſiſtance of mechanical preſſure, be rendered ſo hot as to melt lead, tin, and other bodies, a heat not much inferior to the loweſt degrees of ignition: ſteam from water in the eolipile is ſaid to have been ignited. Dr. Black has alſo ſeen the vapour of water ſo heated, by being thrown into the aſh-pit of a furnace, as to produce in riſing through the vent a very tranſparent flame.

OF COMBUSTION.

Combuſtion is an effect alſo of fire, though not quite ſo univerſal as the preceding: it is not eaſy to convey an accurate idea thereof by a definition, as it is a collection of various phenomena, which take place in the operation of fire on in-

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flammable ſubſtances, the principal of which are a continuance or augmentation of heat, an agitation or inteſtine motion, the emiſſion of light generally in the form of flame, and a total change in the matter burned: here fire overcomes it's fuel, breaks it's nature, alters it's ſtate, and changes it into flame and light.

Combuſtion has been diſtinguiſhed into three ſtates, inflammation, ignition, and detonation.

Inflammation takes place when the body or parts thereof are either in an aeriform ſtate, or can be raiſed into vapour by the ſimple heat of combuſtion, and the flame is greater in proportion as the combuſtible body is more volatile. Thus the flame of a candle is kept up by the volatilization of the tallow or wax, which is effected by the heat of the combuſtion.

Ignition takes place when the combuſtible body is not in an aeriform ſtate, nor ſuſceptible of aſſuming that ſtate by the heat of combuſtion.

Detonation is a ſpeedy and rapid inflammation, which occaſions a noiſe by the inſtantaneous formation of a vacuum.

There is no phenomenon in nature which has more engaged the attention of philoſophers, nor which has more puzzled them to account for, than combuſtion. The moſt oppoſite and contradictory theories have been invented to account for it, but in a very unſatisfactory manner; ſome light has been thrown on it by the diſcovery of dephlogiſticated, pure, or vital air.

You will obſerve a great difference in combuſtible bodies; ſome burn briſkly with a luminous flame, as oils, woods, reſins, bitumens; others burn without ſenſible flame, as many of the metals, and charcoal, if well made; others conſume ſlowly without ſenſible ignition, though with heat, as in certain ſubſtances. In all theſe caſes, when the combuſ-

combuſtion is over, the body burned is reduced to a ſubſtance of a quite oppoſite nature, which cannot be ſubjected again to the ſame proceſs, being quite uninflammable: it may indeed be cooled and heated in the uſual manner, but is no longer inflammable. Such is the nature of inflammable bodies, that when heated to a certain degree, they not only become hot, but by proper management they may be heated to any degree, and the heat which is thus generated, may be communicated to other bodies without any loſs of heat to the inflammable bodies.

The reſidue of the combuſtion is always heavier than the body itſelf before it was burned, as is more particularly the caſe in thoſe that are fixed, not volatilized in the fire. Some ſubſtances ſeem to be an exception to this, as in the open air they burn totally away, without leaving any reſiduum, or a reſiduum leſs weighty than the original ſubſtance. This, however, will not be found to invalidate in the leaſt the poſition in queſtion; for on a careful examination, you will find that ſo far from a total conſumption, there is not any conſumption at all: the ſubſtances would indeed ſeem to be annihilated, if you do not bring the volatile parts into the account. Spirits of wine and ether burn without leaving any reſiduum in the veſſels that contain them, the matter they conſiſt of is volatilized and diſperſed; but if proper means are uſed to collect the product, it will be found in general to exceed the weight of the matter employed. The reſiduums of combuſtion may, therefore, be diſtinguiſhed into two: 1. Thoſe whoſe reſults are fixed. 2. Thoſe which afford volatile and fugacious ſubſtances. In the firſt caſe, where metals are calcined, oils rendered rancid, and in the production of certain acids, ſuch as the phoſphoric, vitriolic, &c. the increaſe of weight is

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eaſily aſcertained. In the ſecond, it is indeed more difficult to weigh all the reſults of combuſtion, and conſequently to aſcertain the augmentation in weight. Yet if the combuſtion be made in inverted veſſels, and the whole of the products be collected, it is found that they are augmented in weight: their augmentation of weight is ſtrictly proportional to that of the air they abſorb.

In order to aſcertain combuſtion, or detain and eſtabliſh a ſource or circulation of fire in the ſame place, it is neceſſary, firſt, that fire reſide in ſome ſolid or fluid matter. Secondly, that the air be freely admitted to it. Thirdly, that to introduce fire into the combuſtible body, it muſt be heated to a certain degree.

That the firſt and third circumſtances are neceſſary, is ſelf evident, for without fire there can be no combuſtion, and without heat applied, you could not produce that fiery commotion by which phlogiſton is diſengaged, and the ſurrounding air is decompoſed. It is ſcarce neceſſary to prove that air is required to ſupport combuſtion.

Let us inflame this ſpirit of wine, and then put over it a receiver containing only a ſmall quantity of air, and you ſee how ſoon the inflammation ceaſes. Plunge that bright burning piece of charcoal into this veſſel, which contains highly rectified ſpirit of wine, and you ſee it is as effectually quenched as if it were plunged into water. If you take another coal, and dip it in the ſpirit, ſo that part remain above the ſurface, the ſpirit will then catch fire; but ſtill the flame will confine itſelf to the ſurface, acting only on thoſe parts of the fluid which are contiguous to the air. You have ſeen that a candle that burns briſkly in the open air, will ſoon be extinguiſhed under a receiver.

On the other hand, you know that fire is quickened by a blaſt of air; and it is an eſtabliſh-

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ed law of nature, that as ſoon as fire begins to ſpread itſelf, *a ſtream of air ruſhes in from all ſides to ſupport it;* and the larger the fire is, the ſharper is the indraft of air: ſo that combuſtion is the joint action of fire and air; between theſe a double motion is maintained, an expanſion outwards, and a preſſure inwards. That there is an action outwards, is evident, 1. From the heat propagated through the air, which at a conſiderable diſtance from the fire itſelf will act as fire, and inflame bodies, when it is reflected from a concave ſpeculum. 2. From the ſhadow which an opake body caſts behind it by intercepting this matter. 3. The continual current of air in a contrary direction; a ſilk handkerchief, or any other light body, held near a fire, will be carried into it; and the ruſhing of the air through all the joints and apertures of the doors and windows of a room, heated by a fire, is ſenſibly felt.

OF THE NATURE OF ATMOSPHERIC AIR.

We muſt now for a moment proceed to the conſideration of atmoſpheric air; this you muſt have already concluded to be a mixture of every ſubſtance capable of retaining an aeriform ſtate in the common temperature, and under the uſual preſſure it experiences. Theſe fluids conſtitute a maſs, in ſome meaſure homogeneous, extending from the ſurface of the earth to the greateſt height hitherto attained, of which the denſity continually increaſes in the inverſe ratio of the ſuperincumbent weight. It is my intention here to give you ſome account of the compoſition of the inferior ſtratum of air which we inhabit. Modern chemiſts have made great advances in this reſearch, and atmoſpherical air has been more rigorouſly examined than any other ſubſtance of this claſs.

They endeavour to prove that atmoſpheric air conſiſts

consists of two aeriform fluids, one of which is capable, by respiration, of contributing to animal life, and in which metals are calcinable, and combustible bodies will burn; while the other is endued with directly opposite qualities; it cannot be breathed by animals, neither will it admit of the combustion of inflammable substances, nor of the calcination of metals: the first of these is called *pure vital or dephlogisticated air*; it is compounded of a peculiar principle of fire, to which last it owes it's aerial form. The first principle unites with the combustible body, and by that means changes it's nature, and adds to it's weight, while fire is disengaged in heat and light. The other principle, or constituent part of *vital air*, always forms acids by uniting with combustible bodies, and has therefore been called by Mr. Lavoisier the oxyginous or acidifying principle:* the nature of this air will be more clearly apprehended when I treat of *elastic or aeriform fluids*. It has been computed from observations, that pure air constitutes about one fourth part of our atmosphere, and that this small part alone is considered as the principal agent in combustion.

Let us now consider the principles on which fire is supported by air; these we shall find to be, first, it's pressure, which keeps the fire together in a body, and prevents it's dissipation; by this effect of the air the fire is concentrated, and it's splendor much increased. You have seen that the electric spark is bright and vivid as lightning, when it explodes in the air, but that it exhibits only a faint diluted silent stream in vacuo. I have also shewn you how soon the fire, with which water is impregnated, escapes, and how soon it cools in vacuo. The

* This is according to the modern French theory, some parts of which I now think dubious, and other parts erroneous, as will be seen in the course of these Lectures.

The outline by which the flame of a candle is ſo well defined, can only be attributed to a preſſure which acts equally on every ſide; and this preſſure can be no other than that of the air, as you may eaſily convince yourſelves by carrying the candle forwards, when you will find the ſide of the flame that meets the air will be bright and well defined, but the ſide that follows will be more ragged and diluted.

This ſight is ſo familiar that we pay but little attention to it; yet it is matter of aſtoniſhment, that a fluid ſo weak as fire might be ſuppoſed to be, on account of the infinite ſubtlety of it's parts, and whoſe exiſtence has been denied by ſome, becauſe they cannot weigh it in a pair of ſcales, ſhould be expanded itſelf, and expand the air with all that force which experiment demonſtrates. To illuſtrate this, let us ſuppoſe the atmoſphere preſſing upon the flame of a candle with half it's force, that is, with a weight equal to ſeven pounds on every ſquare inch; if there be a ſphere of ſuch flame, whoſe diameter is one foot, the air would compreſs it's ſurface with a force equal to 3164 pounds, yet fire maintains it's dimenſions with eaſe againſt a compreſſive power, which ſeems more than ſufficient to drive it back to it's central point.

Secondly, the uniform preſſure of the air on the ſubſtance is changed, and an influx thereof occaſioned by the heat firſt applied to the combuſtible body, by which influx a continual ſupply of freſh air is ſupplied; between the impulſe of this towards the center of the fire, and the continual expanſion of the fire outwards, a conſiderable agitation is occaſioned, which facilitates the combuſtion: the more violent the re-action of the air is made, the greater is the action of the fire upon the air.

Thirdly, experiment now clearly proves, that the ancients were right in the opinion which they univerſally maintained, that air ſupports fire as a *pabulum*, that is, that it actually parts with ſome

of it's ſubſtance to ſupply freſh matter, which increaſes, and becomes part of the fire. In the conflict between the air and the fire, the fire is increaſed, and the air is diminiſhed; for as fire acts upon air, ſo air re-acts upon fire: the latter of theſe is well known, the former will be evident from experiments.

You may ſhew that air is diminiſhed by the proceſs of combuſtion, by throwing the focus of a burning lens on the combuſtible body, when contained in a glaſs receiver inverted in water; when the apparatus is grown cold, the water will be ſeen to riſe up a ſhort way into the receiver. I have already ſhewn you, in Lecture IV, the diminution of air when candles burn under a receiver. Here are ſome receivers with mercurial gages adapted to them; to render this effect more ſenſible, you have only to take care and place the receivers as expeditiouſly as poſſible over the matters already kindled. We will place this receiver over this piece, and you will obſerve the ſame effects you noticed when we tried the flaming candle; the gage is firſt depreſſed, and then riſes about an inch and an half. From theſe experiments, it appears that the larger and briſker the fire in equal ſpaces, let the fuel be what it will, the greater is the conſumption of air; and though different kinds of fuel may occaſion ſome critical differences, the general effect is from the air, and not from the fuel.

I may now attempt to ſhew you what portion of air is abſorbed, and which part of it furniſhes ſo much aſſiſtance in the combuſtion of bodies. You have already ſeen that fire, when in a ſtate of combination with any ſubſtance, does not give any ſigns of heat; and that the heat is greater, and it's effects more rapid, in proportion as more fire is ſet at liberty and diſengaged. I have alſo told you, that atmoſpheric air is formed of two aeriform fluids, one

one of which, *vital air*, is neceſſary to combuſtion, and without which it cannot be carried on, while the other, phlogiſticated air, is altogether improper for combuſtion; to the former of theſe then, or *pure vital air*, we muſt look for aſſiſtance furniſhed in combuſtion, and the air abſorbed. You know alſo that every aeriform fluid is ſuch, principally on account of the fire combined with it's baſe; now pure air contains a great quantity of fire combined with it's baſe. In the act of combuſtion there is an influx of air to the heated body, at the ſame time that the heat applied to the combuſtible ſubſtance puts in action the fire contained therein, breaks it's union with the ſubſtance, and weakens the aggregation of it's parts; the fire from without, or in the air, unites with the fire diſengaged from the ſubſtance, the pure air is thus decompoſed, it's baſe or oxigene unites with the burning body, while the fire, being alſo diſengaged, is united with the fire that commenced the inflammation. From hence there reſults an augmentation of heat, which diſpoſes a great number of particles of the burning body to combine with particles furniſhed by the air, with which it is continually ſupplied, and without this ſupply the fire would go out. In this ſeparation of the air, the fire combined with it eſcapes, and manifeſts itſelf by it's uſual characters, heat, light, and flame; and the more parts that are combined and fixed in a given time, the more fire will be diſengaged, and the more rapid and brilliant will be the inflammation.

In all combuſtion vital air is decompoſed, fire diſengaged, and conſequently heat produced; the heat is greater or leſs according to the nature of the burning body; for according to the experiments of Meſſrs. Lavoiſier and De la Place, one ounce of charcoal conſumes, in burning, 4037.5 cubic inches of vital air, and forms 3021.1 inches of

of fixed air. This ounce of charcoal consumes then 3 oz. 4 grs. of vital air, and forms 3 oz. 5 grs. of fixed air.

From what has been said, it appears clearly, 1. That combustion is eminently promoted by vital air, which maintains combustion. 2. That the more fire is disengaged, the stronger will be the heat produced. 3. That the best method of producing violent heat consists in burning bodies in the purest air. 4. That fire and heat must be more intense as the air is more condensed: and, 5. That currents of air are necessary to maintain and expedite combustion.

You may from these principles easily account for the effect of the Argand or cylinder lamps; the current of air, which is renewed through the tube, supplies fresh air every instant, and by continually supplying a new quantity of vital air to the flame, a heat is produced sufficient to ignite the smoke.

In the same manner you may account for the vehement action of a blast of air upon fire, and the parts of fuel. Some metals melt more easily than others; iron is a metal which requires, for fusion, the utmost violence of fire: notwithstanding this difficulty, let a bar of iron be laid in a smith's forge till it has got what they call a white heat; when it is as bright and sparkling as it can be made, let it be taken out of the fire: then let a blast of air from a common pair of bellows be strongly blown against the heated extremity of the iron, which, instead of being cooled by the blast, will become more white and shining than before, till by degrees it rolls about in a liquid form, sending out brilliant sparks in all directions, and falling with frequent drops to the ground. If a cannon bullet be heated in the like manner, by a large pair of forge bellows, it affords a glorious spectacle, which can be conceived only by those who have seen it; the eyes are

are dazzled with the ſight as when we look upon the ſun.

The ſmiths, whoſe buſineſs lies at the forge, are ſo well acquainted with this effect of a blaſt of air againſt ignited iron, that they cautiouſly avoid expoſing the metal too near to the noſe of their bellows. A fire-man, who is but green in his profeſſion, is very apt to be catched with this accident from his bellows, by which he utterly ſpoils the ſtuff he works upon, by giving it what they call the wind rot. In theſe rapid combuſtions the ſame quantity of heat and light is produced in a ſecond of time, as in the ordinary methods would require a much longer time.

This you will ſee pleaſingly exhibited in the next experiment, firſt made by Dr. Ingenhouz. I take this piece of fine iron wire, twiſted into a ſpiral; I fix one of the extremities to the cork at the top of the bottle, and to the other extremity a piece of tinder; I now fill the bottle with vital air, light the tinder, and introduce it and the wire as expeditiouſly as I can into the bottle, ſtopping it with the cork. The moment you ſee the tinder comes in contact with the vital air, it begins to burn with intenſity: it has now communicated the inflammation to the iron wire, which has taken fire; obſerve how rapidly it burns, and what brilliant ſparks it throws out; theſe fall to the bottom of the bottle, and though they become black in cooling, yet they retain a degree of metallic ſplendor. The iron thus burnt is more brittle than glaſs.

With the aid of vital air Profeſſor Lichtenberger ſoldered the blade of a knife to a watch ſpring. Meſſrs. Lavoiſier and Erhmann have ſubjected almoſt all known bodies to the action of fire maintained by vital air, and have produced effects which the burning glaſs could not have operated.

Mr. Foſter, of Gottingen, found the light

 of

of the glow-worm ſo beautiful and bright, in vital air, that one ſingle inſect afforded light ſufficient to read a book printed in a ſmall character.

OF FLAME.

This is in general conſidered as a luminous vapour, or in other words, as the vapour of a ſubſtance raiſed by fire, and heated to ſuch a degree as to emit light copiouſly.

Bodies are capable of emitting flame only in proportion to the quantity of vapour that riſes from them: thus wood, coals, &c. which emit a great quantity of vapour, flame violently; while lead, tin, &c. which emit but a ſmall fume, can ſcarce be perceived to flame at all.

To this rule there are, however, ſome exceptions; ſome vapours ſeem to be in their own nature uninflammable, and capable of extinguiſhing flame, as thoſe of water, as the mineral acids, ſal ammoniac, arſenic, &c. while others, as ether, ſpirit of wine, &c. take fire on the ſlighteſt approach of a flaming ſubſtance: the laſt exhibit a remarkable phenomenon, as they cannot be made to flame without the approach of ſome ſubſtance previouſly in flames: thus, ſpirit of wine poured on a red-hot iron, though immediately diſſipated in vapour, will not flame; but if a burning candle touch it's ſurface, the whole is ſet in a flame at once. The caſe is however otherwiſe with oils, eſpecially of the groſſer kind, for their vapours will readily be changed into flame by the mere increaſe of heat, without the approach of any flaming ſubſtance.

There is probably, however, no kind of vapour but what may be converted into flame, provided it be expoſed to a ſufficient degree of heat. Even the vapour of water, made to paſs through burning coals, is ſaid to produce a bright ſtrong flame.

flame. It has been conjectured that when ſmoke is converted into flame, the latent fire, which had combined with the vapour, is diſengaged, and adds to the quantity of ſenſible heat already manifeſted.

If a veſſel full of oil be ſet over a fire, a ſmoke or vapour begins to riſe from it, which grows gradually thicker and thicker, and at laſt begins to ſhine at ſome places near the ſurface of the oil; the heat does not exceed 400 degrees of Fahrenheit: but if a lighted candle be held in the ſteam for a moment, the whole is immediately converted into flame with ſomething like an exploſion, after which the oil burns quietly until it is all conſumed.

OF THE FLAME OF CANDLES.

This ſubject has been already very well conſidered by Mr. Nicholſon,* from whom we find that *wax*, being already combined with a portion of vital air, does not burn with ſo luminous a flame as tallow or oil; but that it poſſeſſes a very great advantage in the fabrication of candles, becauſe it requires a greater degree of heat to melt it than either of the other two ſubſtances.

To underſtand this advantage, you muſt conſider that oils do not take fire unleſs they be previouſly volatilized by heat: the oil riſes between the fibres of the wick by what is called capillary attraction. Heat is applied to the extremity of the wick, which volatilizes and inflames a portion of the oil; as this is diſſipated by combuſtion, another portion riſes and ſupplies it's place, by being heated and inflamed: in this way a conſtant combuſtion is maintained. A candle differs, however, from a lamp, in one very eſſential circumſtance, that the tallow is liquified only as it comes to be in the vicinity of the conflagration, and this fluid is re-

 tained

* Nicholſon's Firſt Principles of Chemiſtry, p. 487.

tained in the hollow of the part which is ſtill concrete, and forms a kind of cup. To carry this fluid off as faſt as it is formed, it is neceſſary to have a thick wick, otherwiſe the oil will run down the ſides of the candle; but as wax is not ſo fuſible as tallow, the wick of a wax candle may be made much thinner than one made of tallow.

Let us obſerve the difference in the appearances produced by a thin and a thick wick. You obſerve that in this candle with a thick wick, ſnuffed ſhort, the flame is perfect and luminous, (which will be the caſe, unleſs the diameter be very great, when there is an opake part in the middle, and where the combuſtion is impeded for want of air). As the wick becomes longer, the ſpace between the top of the wick and the top of the flame is diminiſhed; conſequently the oil paſſing off at that extremity having leſs ſpace of ignition to paſs through, is not ſo completely burned, and paſſes off partly in ſmoke: this evil continues to increaſe until at length the upper part of the wick projects beyond the flame, and forms a ſupport for an accumulation of ſoot, which is afforded by the imperfect combuſtion. A candle in this ſituation affords ſcarcely one tenth of the light which the due combuſtion of it's materials would produce; and tallow candles, on this account, require continual ſnuffing. But on the other hand, if you obſerve this wax candle, you obſerve that as the wick lengthens, the light indeed becomes leſs, and the cup is filled with melted wax. The wick, however, being thin and flexible, does not, as you ſee, long occupy it's place in the center of the flame, neither does it, when there, enlarge the diameter of the flame, ſo as to prevent the acceſs of air to the internal part; but bending on one ſide, when it's length is too great for it's vertical poſition, it's extremity comes into contact with the air, and is burned to aſhes, excepting

excepting only ſo much as is defended by the continual afflux of melted wax, which is volatilized and completely burned by the ſurrounding flame. We ſee, therefore, that the difficult fuſibility of wax renders it practicable to burn a large quantity of fluid by means of a ſmall wick; and that this ſmall wick turning on one ſide, in conſequence of it's flexibility, performs the office of ſnuffing itſelf in a much more accurate manner than it can ever be performed mechanically.

Some further conſiderations on a ſubject ſo intereſting, and ſo often before mentioned, will I hope not prove unacceptable.

When a candle is for the firſt time lighted, (which muſt be done by the application of actual flame) a degree of heat is given to the wick, ſufficient firſt to melt, and next to evaporate the tallow ſurrounding it's lower ſurface; and juſt in this part the newly generated vapour is, by admixture with the air, converted into a *blue* flame; which almoſt inſtantaneouſly encompaſſing the whole body of the vapour, communicates ſo much heat to it, as to make it emit a yellowiſh white light. The tallow now liquified, as faſt as it boils away at the top of the wick, is, by the capillary attraction of the ſame wick, drawn up to ſupply the place of what is evaporated. The congeries of capillary tubes, which forms the wick, is black, becauſe it is converted into coal; a circumſtance common to it with all other vegetable and animal ſubſtances, when the oil which enters into their compoſition having been decompoſed by combuſtion, the more fixed part is by any means whatever covered and defended from the action of the air. In this caſe, the burning ſubſtance owes it's protection to the ſurrounding flame. For, when the wick, by the continual waſting of the tallow, becomes too long to ſupport itſelf in a perpendi-

cular ſituation, the top of it projects out of the cone formed by the flame, and thus being expoſed to the action of the air, is ignited, loſes it's blackneſs, and is preſently converted into aſhes.

The part of the flame which comes into contact with the air, appears of a *blue* colour. The inner part of the flame differs from the outer, in being much denſer, and emitting a ſtrong yellowiſh white light, which has been called the light of ignition; while on the other hand, the blue has been ſuppoſed to conſtitute the light of inflammation. Theſe two parts of the flame, differing not only in colour, but almoſt in every other property, ought to be diſcriminated from each other by different epithets. The interior part may be conſidered as (what it really is) an ignited body, and the light emitted by it may be called the light of ignition; while that proceeding from the exterior portion, may be denominated the light of combuſtion, for it is properly in this part of the flame, that the proceſs of combuſtion is carried on, and by that means a *tertium quid* produced; the ſucceeding phænomena being rather ſequels to, than making part of this proceſs. When more vapour aſcends than can combine with the air in a given time, the remainder by the continued action of the blue flame ſurrounding it, ſuffers an accumulated degree of heat, and is ignited.

OF PHLOGISTON.*

It will be proper here to take notice of a principle which modern chemiſtry aſſumes, as neceſſary to the exiſtence of inflammable bodies, as that which renders them ſuch, or in other words as the *principle of inflammability*. The French chemiſts have indeed lately attempted to prove from the production of water, when inflammable and vital

* This principle will be conſidered more fully when we treat of elaſtic fluids.

vital air are mixed in due proportions, and kindled in a close vessel, that there was no such principle as phlogiston; and they have endeavoured to propagate and maintain their inference by coining new terms, and forming a new language, to render their opinions universal, and subjugate the mind of man to their tenets. How far there is any foundation for their discarding phlogiston, reasoning from their own experiment will be, I hope, rendered evident, by the following part of this Lecture; which is principally extracted from Dr. Hutton's "Dissertations on different subjects of Natural Philosophy."

If you wish to see the errors in their reasoning, the falsity of their principles, and the vanity and weakness of their assumptions fully proved, I must refer you to the excellent letters published by *Mr. de Luc*, in the Journal de Physique for 1790, 1791, and 1792.

Not content with the discoveries they had made, they have endeavoured to explain combustion upon a misapplied and erroneous principle. They assert in theory, though they contradict the assertion in explanation, that *vital air* contains in itself the principle of fire, and that it is the fire lurking therein, that immerges upon the combination of this air with the particular substance of the burning body. Placing the light and heat all in the vital air, they consider the phlogistic principle existing in the body itself as unnecessary, and have therefore proscribed it, in their tyrannical arrangement of the subject.

I think the considerations I am going to lay before you, will prove, that their theory does not explain the principal appearances for which the term phlogiston has been adopted in science, and that they have therefore been only introducing er-

ror, by imputing certain effects to improper and inadequate causes.

The doctrine of phlogiston, as understood by modern chemists, implies, that a quantity of fire, or the matter of light and heat, is occasionally contained in bodies as *a part of their composition*; and that these bodies possess this naturally diffusive substance, upon *a different principle from that of heat*, or any other besides this, which is peculiar to itself. These bodies are called phlogistic bodies.

Phlogiston, thus considered, seems to form a substance *sui generis*, differing from every other substance in a body. It may be considered as a treasure within them of light and heat, to be dispensed in the absence of the sun, both for the various purposes of necessity and convenience, in the œconomy of the world.

On the supposition of phlogiston, the light which is propagated from a burning body, belonged to that body, and made part of it's substance.

Inflammable bodies lose their luminous substance in burning, after which they can by no means be kindled, unless their luminous substance be again restored to them, which is done by the chemical action of another phlogistic body on the remains of the first. But here also the second body is deprived of it's phlogistic qualities, while it restores them to the first; and becomes as incapable of emitting light and heat in the way of inflammation, as if it had already undergone that process in the most complete manner. Examples of this are found in the burning of zinc, of phosphorus, and sulphur; for after these bodies have lost their light and inflammability, these may be again restored by means of a certain quantity of charcoal, which is thereby consumed, or loses it's combustible principle.

From

From the *important changes* produced in an inflammable body by burning, as well as from the amazing quantity of *light* emitted in that operation, it is inferred, that the body has loſt *a great and material part* of it's ſubſtance. It is allowed, that bodies in burning or calcining are combined with a large quantity of atmoſpheric matter, which changes all their ſenſible qualities; but it is alſo contended, that they are more changed than what they ought to be from the additions they have received, or the new combinations which have been formed.

As the weight of bodies is not diminiſhed by burning, it may therefore be juſtly ſuppoſed, that there is in the conſtitution of inflammable bodies a peculiar ſubſtance productive of their eminent qualities, *a ſubſtance diſtinct from all matter that gravitates*, yet a ſubſtance by which our organs of ſenſation are immediately affected.

THE REALITY OF PHLOGISTON PROVED BY DECOMPOSITION OF WATER.

In the well conducted experiment of Mr. Lavoiſier, we will ſuppoſe for the preſent the analyſis of water to be well eſtabliſhed; but in thoſe experiments, by which the compoſition of water is made to appear, the *phlogiſtic principle* will be found alſo to have acted it's part, and you will find this elementary ſubſtance in that very operation by which the compoſition of water was detected.

There are ſome circumſtances concerning this important experiment, which ſeem to have eſcaped the attention of the excellent chemiſts who made it, the neglect of which renders their theory imperfect, their reaſonings inconcluſive.

In

In this inquiry, we abſtain as much as poſſible from every thing foreign to the ſubject of phlogiſton, and we only inquire into the nature of water, ſo far as the production thereof is connected with the decompoſition of that particular phlogiſtic body we are to examine; we therefore need not conſider the truth of their theory, relative to the nature and conſtitution of water. The doctrine of phlogiſton is as independent thereof, as it is contrary to their deductions from the theory of water.

One unknown principle, or element of water, is contained in the inflammable air; the other element of water, the acidifying principle, is in the pure vital air; that is, there are in vital air and inflammable gas, two ſubſtances extremely attractive of each other, which when ſuffered to unite, ſaturate each other, and form a ſubſtance perfectly different from it's conſtituent parts.

Or to be more particular, that inflammable air and vital air being mixed in due proportion, and this mixture *kindled* in a cloſe veſſel, the two elaſtic fluids diſappear, and a quantity of water equal to the weight of the two bodies which were incloſed, is found in the veſſel after cooling. From hence it has been concluded, that water is compoſed of vital and inflammable air, and that there is not required any *phlogiſtic* ſubſtance, in order to explain the phænomena of burning.

That there is an immenſe production of light and heat, where the two conſtituent principles of water are united, is allowed; and hence moſt chemiſts are perſuaded of the exiſtence of a combination of fire with the compoſing parts, different from what is called latent fire, and conſtituting what they call phlogiſton. This is explained in the French theory, by the term *calorique*, uſing the term here, as nearly ſynonimous to latent fire. But in this ſenſe, the explanation is inadequate, for

ſor the common doctrine of latent fire does not ſeem ſufficient for the ſolution of the phænomena. For the materials mixed in this experiment do not unite without inflammation, and when made to unite, by being kindled, there are certain appearances not to be explained by the theory of latent heat.

Now here it becomes an object of inquiry, what ingredients vital and inflammable air contain, which prevent their union. Conſiſtent with what is known of the laws of nature, this cannot be attributed to their latent fire.

It is by this that they are maintained in their elaſtic ſtate; it cannot therefore be ſuppoſed, that an increaſe of elaſticity, and of courſe latent fire, can be any means of ſeparating that fire; that when more is wanted to maintain them in that ſtate, what they have already ſhould be ſeparated from them, or even that an increaſe of ſenſible heat ſhould be the cauſe of ſeparating the latent fire.

There is, indeed, no foundation for ſuppoſing that the conſtituent parts of water in this experiment are before inflammation kept ſeparate by latent fire; but *that they are combined with other ſubſtances* in ſome particular ſtate, by which their natural union is deſtroyed. This leads us to examine what happens, when by inflammation the *inflammable ſubſtance is deſtroyed*, and the two conſtituent parts of water are united together.

Of all the operations of man exerting his ſkill in nature, the inflammation of combuſtible bodies is moſt worthy of attention. From a ſmall quantity of matter, he produces an *immenſe power* of heat; from nothing almoſt he makes an artificial ſun, and diſpenſes light without the aid of any thing, but what is in the compoſition of the body to be burned.

But what is it that man does on this occaſion? He giveth the ſpark, and all the reſt is done by nature. An amazing quantity of light and heat is thus

thus produced, and the greateſt poſſible change takes place in what remains. The light and heat which before had been in the combuſtible materials, are now diſperſed in the univerſe, and what remains of thoſe bodies, has loſt the power of producing light and heat.

Here is a fource of power of which man has availed himſelf; by knowing the laws of nature, he rends the hardeſt rocks, and raiſes rivers of water from the bottom of his mine, by the action of heat produced in the inflammation of combuſtible bodies.

But no ſooner is the combuſtion completed, than the body *has loſt it's power* of inflammation, it is left a maſs of gravitating matter, no longer ſerviceable to man as an addition to his natural ſtrength. How then is the body to recover this power? It was by emitting heat and light, that the burning body loſt it's power; it was by applying fire, that the decompoſing operation was excited. We cannot therefore look for the reſtoration of that power by means of fire or heat. Nothing but the operations in nature can reſtore again that power, by ſupplying it with a phlogiſtic ſubſtance, again to be conſumed, by which a body is formed, which may in a ſimilar manner be ſerviceable to man and the world.

Light and heat have been ſeparated on the union of the two airs in forming of water, and there is no reaſon for preſuming that the latent fire was the cauſe, which prevented their union; and further on inquiry it will be found, that there is no reaſon to ſuppoſe, that the matter ſeparated, and acting as heat and light, was what had been retained before as latent fire.

That the latent fire of theſe aeriform ſubſtances would be ſufficient to heat a ſolid body, equal to the moſt intenſe degree of incandeſcence, will be readily

dily granted. But you muſt remember in the caſe before us, that where the water is formed, and heat appears, the two aeriform fluids, or rather the water into which they are changed, does not *concrete* into a ſolid ſubſtance, but is at firſt in the form of a *vapour* or ſteam, which occupies as much ſpace as the two aeriform fluids did, before they acted on one another, and *will therefore require the whole, or nearly the whole of their latent fire*, to give it that form, without being made ſenſibly hotter than they were before; but the flaſh, and other phænomena in the operation, ſhew that there is a ſudden manifeſtation of heat, when the watery vapour is formed. This cannot be produced by this latent fire, which only becomes ſenſible, when the fluid containing it is condenſed or congealed.

Latent fire cannot be the cauſe of the inflammation which takes place upon the compoſition of water, for on this ſuppoſition, they muſt have emitted the light and heat, either in their condenſed ſtate of water, or in the ſtate of vaporific expanſion. If in the condenſed ſtate, the luminous body muſt be exceeding ſmall, which is not the caſe, being a great flame. If on the other, they emit it in the expanded ſtate, they emit a quantity which we cannot ſay was their latent fire, for their elaſtic fluidity ſtill ſubſiſts, to which ſtate it is abſolutely neceſſary. It muſt therefore proceed from ſome other modification of the ſolar ſubſtance or fire in their bodies, which may with propriety be called a phlogiſtic ſubſtance, before it's emiſſion from theſe aeriform bodies, as it is certainly fire the moment it is ſet at liberty.

Beſides, there are ſolid denſe ſubſtances (as *ſulphur and iron)* which can be ſuppoſed to hold but little latent fire, which, when they are kindled in vital air, emit apparently as much light and heat as if they

they had been ſubſtances in an extremely expanded ſtate: ſo that if latent heat be the cauſe, it muſt be attributed to the air alone; on which unreaſonable ſuppoſition, the inflammable air in the experiment we have been conſidering would contribute nothing to the production of light and heat.

According to the French theory, charcoal is conſidered as an uncompounded ſubſtance, which, in burning, is ſuppoſed to be ſimply combined with vital air; *here alſo* the light and heat produced in burning the charcoal, remain to be explained; for here, inſtead of finding an expanſive fluid rendered concrete, we find a ſolid concreted ſubſtance expanded into the elaſtic form of fixed air. We have therefore to inquire how, on the new theory, they can account not only for the light and heat of burning, but for the latent fire required to maintain the elaſtic fluid. It muſt explain the creation of the light, the ſenſible heat, and the latent fire.

If more were neceſſary on this head, I might refer you to Mr. Berthollet himſelf, the founder and ſupporter of the French ſyſtem. In his treatiſe on the art of dying, he owns "that the received principles of heat can only be conſidered as ſuppoſitions." After this confeſſion, it is to be hoped the advocates for the new theory will be more modeſt, and not ſo haſty, as to conſider it demonſtrated. Again, we find him own in the ſame work, that "the heat of combuſtion does not proceed ſolely from the vital air, but is alſo furniſhed by the burning body."

This is confeſſing all that we contend for, namely, that in combuſtion the *light* and *heat* is furniſhed partly by the combuſtible body, partly by the vital air; but the greateſt quantity by the combuſtible body. Thus is the diſpute reduced to one of words, and as far as relates to this point the

the *calorique combiné* is nothing more than *phlogiſton,* or the inflammable principle.

Before I conclude this part, I ſhall lay before you a paſſage of Mr. de la Metherie, which confirms what has been already mentioned; namely, that it is not the latent fire that ſupports the elaſtic ſtate of vital air. He firſt ſhews that this aſſertion is contrary to their own theory, the proof of which would lead me into an unintereſting detail; he then ſhews that the effects of vital air cannot ariſe from the combined caloric, which renders this air elaſtic; for there are numerous phenomena where vital air, not being in an elaſtic ſtate, produces the ſame effect. The vital air in the nitrous acid, in the dephlogiſticated marine acid, and in metallic calxes, is not in an elaſtic ſtate, yet produces the ſame effects as when it is. All the combinations of nitre with combuſtible bodies burn with activity. What a quantity of light and heat is diſengaged from gunpowder by the ſmalleſt ſpark! If the powder be made with dephlogiſticated marine ſalts, it will inflame and explode merely by friction, &c. &c. M. de la Metherie brings forward many other important inſtances to prove the ſame point. I ſhall mention but one more: the caloric (fire) that keeps vital air in an elaſtic ſtate, does not differ from the caloric which ſupports other gaſſes in the ſame ſtate; why do they not alſo exhibit light and heat when they loſe their elaſtic ſtate? From theſe reaſons it is plain, that we muſt not conſider the effects of vital air in combuſtion as owing to the combined fire, which is the cauſe of it's elaſticity.

Senſible heat and latent fire are mutually convertible; but from what has been ſaid, as well as from other reaſons, it ſeems clear, that there is not a ſufficient quantity of commutable fire in vital air to explain the incandeſcence of bodies; and conſequently,

ſequently, that they do not burn on account of latent fire. But I ſhall alſo now ſhew you, that when bodies emit light, in conſequence of the decompoſition of their phlogiſtic ſubſtance, this *luminous* matter had not been derived immediately from any ſpecies of heat; but that it is a luminous emanation proper to the decompoſition of phlogiſtic ſubſtance, and is the ſenſible effect and proof of that operation.

This is proved, firſt, by ſhewing that when inflammable bodies in a ſtate of vapour are kindled, it is not the vapour heated to incandeſcence that emits the light, *but the intenſe illumination that gives the heat*. Secondly, bodies which have no more than the common temperature of the atmoſphere, may emit light by the emiſſion of their phlogiſtic ſubſtance.

Now by conſidering the flame of a candle, you will find proofs of the firſt caſe. For if it be the emiſſion of light which heats the elaſtic fluid in contact with the luminous body, we ſhall find a ſteam of intenſely heated vapour aſcending along the flame of the candle, without having the power to emit light. That this is the cauſe, you may eaſily prove. Take a ſmall bit of clay, like a grain of corn, ſuſpend it by a ſlender wire above the flame of a candle; and let a ſcreen be placed near the candle, ſo as to hide the flame; and you will perceive that the ſtream of heated air, which has no power of illumination, will heat the little body to incandeſcence at a conſiderable diſtance above the flame.

Light may be emitted on the decompoſition of phlogiſtic ſubſtances, not only without ſufficient intenſity of heat to form incandeſcence in any body, but without any perceptible increaſe of heat in the body, which is to emit the light.

Examples

Examples of this may be taken in living animals, which have a power of emitting light; alſo in the dead bodies of animals and vegetables going to decay. It is alſo well illuſtrated by a chemical ſubſtance, phoſphorus; no body burns more fiercely than this, when it is kindled. Yet it may be decompoſed by atmoſpheric air, without burning in the ordinary manner, that is, without acquiring any ſenſible degree of heat, far leſs of one capable of cauſing incandeſcence: this change however is not effected without the body emitting it's phlogiſton in the form of light. Now where are we to ſeek for this luminous matter, but in the reſolution of the phlogiſtic ſubſtance? I have ſhewn that atmoſpheric air does not give it in the form of commutable latent fire. It does not proceed from the increaſed degree of ſenſible heat; we are therefore conſtrained to believe, that in the decompoſition of the phlogiſtic body, the ſolar ſubſtance which had been detained in the phlogiſtic compoſition is liberated, and eſcapes in the form of light.

Thus it is plain, that *phlogiſtic bodies contain a certain quantity of the matter of light and heat, in a different ſtate from that in which the ſame matter is employed, either in the fluidity or expanſion of bodies, and which is not transferable in the manner of ſenſible heat*; and this may be properly termed their PHLOGISTIC PRINCIPLE.

That this ſubſtance has not weight, can only be received as an objection by thoſe who admit the univerſality of gravitation in matter, but can have no influence upon thoſe who deny this principle.

From what has been ſaid we may now gain a clearer view of the different modifications or ſtate of the matter of heat and light in bodies.

Senſible heat is fire in a ſtate in which it is transferable among bodies communicating together by immediate contact; every additional quantity in-

creaſes the volume of the body, the abſtraction of it diminiſhes the volume; it alſo produces in ſenſitive bodies, the ſenſation of heat and cold.

Latent fire is of two kinds; that of fluidity, and that of elaſticity. The *heat of fluidity* is that quantity or modification of fire, which, without either affecting the volume or the ſenſe, cauſes fluidity; that is, converts a hard concreted body into a fluid deſtitute of hardneſs or concretion. This has nothing to do with the preſent caſe, as the bodies are equally fluid, before and after burning. The heat of *fluid elaſticity* is that portion of the commutable and transferable ſubſtance of ſenſible and latent fire, which, inſtead of increaſing the volume in a ſmall degree, or deſtroying the hardneſs, ſeparates it's parts indefinitely, and by which they acquire an elaſtic and expanſive power. You have ſeen that the heat of burning bodies does not ariſe from the latent or expanding heat of the oxygenous gas.

This famous experiment of burning the two airs in the forming of water, ſhews that the phlogiſtic matter in the compoſition of bodies neither adds to their gravitation, nor impairs their weight; for in this experiment, the quantity of light and heat is ſo great a thing in proportion to the weight of the inflammable bodies, that, if this fugitive ſubſtance had any effect upon the gravitation of thoſe bodies to the earth, it muſt have been ſenſible upon this occaſion.

Bodies which poſſeſs the quality of being eminently reſolvible in giving light, are called inflammable, or combuſtible bodies; but as it is often neceſſary to give a name to this transferable ſubſtance, chemiſts have termed it phlogiſton.

OF THE PRODUCTION OF PHLOGISTON.

As phlogiſtic bodies loſe their peculiar ſubſtance by a general and neceſſary operation, there muſt

muſt be another, or contrary operation in nature, whereby they regain it. For as this ſubſtance, whatever it be called, is waſted in burning of bodies, there muſt be another operation by which it muſt be renewed.

It is in animal and vegetable ſubſtances that we muſt ſeek for this productive operation; for water is not more eſſential to the conſtitution of theſe organized bodies, than phlogiſtic matter by which they may be made to burn.

Phlogiſtic matter is abſolutely neceſſary to animal life, for animals muſt have a ſource of heat, which in the œconomy of their nature muſt be in perpetual waſte: of the deſtruction of phlogiſtic ſubſtance, the conſumption of vital air, which neceſſarily happens in the breathing of animals, is a ſufficient proof. This vital principle of the atmoſphere performs the ſame function in the lungs of animals, as in the experiment by which the regeneration of water appears to be ſo beautifully proved. Here then is alſo a waſte of atmoſpheric air, which muſt be again reſtored to the ſyſtem of nature.

Animal bodies, in whoſe operations phlogiſton is conſumed, are ſupplied immediately with this ſubſtance for their food. But as all animals are ultimately fed on vegetable ſubſtances, we are led to look to vegetation, or the proceſs by which theſe ſubſtances are produced. It is here we are to diſcover the ſource of this transferable ſubſtance, which plants ſupply in feeding animals, and which animals conſume in the production of their heat.

Next after animal life, in the conſideration of Divine Providence, is placed the vegetable ſyſtem. The earth is beautifully contrived for their ſupport, and the proper object of the mineral kingdom would appear to be the preparation of a ſoil, in

which plants are to be ſuſtained. The ſolid rock, the moveable ſand, the fluid wind, are all equally adapted to the ſervice of the vegetable ſyſtem; a ſyſtem ſo contrived, as to find in every climate proper ſoil, as well as in every ſoil proper climate.

But ſoil alone will not ſupply the neceſſaries of life to vegetable bodies; the wholeſome influence of the air is as neceſſary to them as to animals, although it ſeems to act on each in a different manner. We have now therefore to examine how far the air corrupted, in it's neceſſary uſe by animals and burning bodies, ſhall be reſtored by that operation of a plant, in which the air is required as a neceſſary condition.

That the atmoſphere is purified by growing vegetables, was a natural conjecture; this is now verified by the accurate experiments of Dr. Ingenhouz, and the beautiful theory of Mr. Lavoiſier, on the compoſition of water. By theſe we find, that in vegetation, phlogiſtic matter is prepared, and vital air given out.

Plants muſt receive their phlogiſtic matter, either 1ſt, from the ſoil into which their roots extend; or 2dly, from the atmoſphere in which they grow; or 3dly, muſt generate it within themſelves, by means of materials received from without.

With reſpect to the firſt means, it is well known, that the fertility of vegetable ſoil is extremely increaſed by the addition of phlogiſtic ſubſtances, ſuch as are found in animal and vegetable bodies; but theſe being ſtill ultimately of vegetable production, it would be in vain to look here for a ſource of phlogiſton to repair the general waſte.

Let us now therefore ſee, what ſupplies may be obtained from the atmoſphere; and here we ſhall turn our view towards the influence of light, for the

the phlogiſtication of vegetable bodies. When you ſurvey the earth covered with ſuch various tribes of plants, and when you obſerve the different foliage of thoſe organized bodies, extended with ſuch art as if deſigned that no ray of light might eſcape without paying it's tribute to vegetation; and when you join to this, the faculty that plants have of turning their leaves always to the light; ſhould we not then conclude, that the expoſing a large ſurface to the atmoſphere for perſpiration is not the only purpoſe for which the foliage of plants, correſponding to the lungs of animals, has been intended.

But more than probability is obtained, when we conſider the invigorating power of light on plants, independent of the effects of heat and air, and the neceſſity of this luminous ſubſtance, though not to the life or vegetation of plants, yet to the proper increaſe and production of vegetable ſubſtances. Here then is the place, where the combination of the ſolar ſubſtance is made for the production of phlogiſtic matter.

To be perfectly aſſured of this, let us examine whether there is any effect proper to phlogiſtic matter, which uniformly attends the expoſition of vegetable bodies to the ſolar light, and exiſts only in conſequence of this illuminating cauſe. Now there is no effect of phlogiſtic matter in bodies more certain, than colour, or blackneſs, by which the incident light is more or leſs abſorbed in the ſubſtance of a body. Hence the production of a coloured ſubſtance in a body which was not coloured before, may be conſidered as an evidence that phlogiſtic matter has been compoſed in that body. But this is the caſe with plants; they only grow coloured, or acquire the green colour of their leaves, in conſequence of being expoſed to the light.

This colouring ſubſtance is not produced in conſequence of vegetation alone; for plants may vegetate in the dark, without acquiring this colour. It is not the effect of heat, like the blackneſs produced in a white vegetable ſubſtance, placed in the focus of a burning lens, becauſe plants growing in the dark, may have equal, or more heat, than thoſe growing in the light, without acquiring any coloured ſubſtance.

This theory may be confirmed alſo by obſerving the effects of the ſun's rays upon dead and living plants. To the living bodies, it's effects are to give colour; on the other to diſcharge it. It is in the organized body of the living plant, that phlogiſtic matter is formed by the combination of the ſolar ſubſtance.

If you find the reſtoration of vital air in the atmoſphere, proceeding in the ſame progreſſion with phlogiſtic ſubſtance, you may conclude that this is the means employed by nature in re-eſtabliſhing the ſalutary quality of the atmoſphere. This and other truths are proved by the ſatisfactory experiments of Dr. Ingenhouz.

Plants growing in the ſun, emit from their leaves a pure vital air, whereas growing in the dark, the production of this ſubſtance, as well as that of colour, is interrupted.

Thus as in the decompoſing of phlogiſton, whether by breathing, or by burning, the atmoſpheric air is corrupted; ſo again, on compounding phlogiſton, by the growing of vegetable bodies expoſed to the light, the atmoſphere is reſtored to it's nature.

So much beauty of order and contrivance have been diſcovered in the œconomy of animal and vegetable bodies ſuſtaining themſelves in forming a certain circulation of matter, and employing the great,

great, the general agents of this world, AIR, LIGHT, HEAT, that nothing can be more interesting or important in the study of nature.

It may be necessary to examine an objection which may be made to this theory, from the experiments of Sir Benj. Thompson, who procured pure vital air in great quantities by exposing silk and various other bodies in sunshine to the water. His experiments, when considered, will be found to give additional proof to this theory; he does indeed shew another source for vital air besides what is procured from the vegetation of the inclosed leaves, but he by no means shews that vital air is procured without vegetation; for vital air is never procured without water becoming green and turbid; but when we find the water becoming green, and animalcules appear, have we not then every reason to presume that the animalcules have been fed on plants, and that those plants emitted vital air?

When in studying the system of nature, we observe, that every thing is in action for some purpose; that opposite powers are continually ballancing each other, or alternately prevailing; and that the general end in view is to contribute every thing requisite for the necessities, for the conveniences of animal life; we find ourselves pleased with this subject of contemplation, and interested in what relates to nature.

We may now endeavour to take a general view of that contrivance which may be perceived in the means employed by Divine Providence for the important operations of sustaining animal life, and forming of the inert mass of this earth a living world.

In this system of organized matter, which is comprehended in the idea of the world, *the emanation of matter from the sun may be considered as one of the prime movers of the machine.* At the same

 time,

time, gravitation, which is another of thoſe powers, would ſoon bring all the matter of this machine to reſt, and would lock up every body in a ſtate of the moſt abſolute inactivity. Conſequently, if we reaſon conſiſtently with our own ideas, it is not either by the one or other of thoſe two great agents alone that the natural operations of this world are conducted, but by the joint action of them both; each, at the ſame time, having it's peculiar office, which it is the buſineſs of ſcience to diſtinguiſh.

Thus that great agent which regulates our planetary ſyſtem, and gives life to nature, acts upon the ſurface of this earth; and it there performs different operations, according to the various conditions in which it acts. Under the form of heat, it ſeparates and diſtends unorganized matter or ſimple bodies, and it ſuſpends the hardneſs or particular attractive powers of their ſubſtance. Organized and ſenſitive bodies, again, it affects with the ſenſations of light and heat; but in another ſpecies of organized living bodies, that is, plants, which have no ſenſe, no knowledge, no means of underſtanding, it produces peculiar effects; it paints the various colours, ſo to ſpeak, of their diſtinguiſhable parts; it gives them their peculiar virtues, which are various ſpecific taſtes and ſmells; and it ſtores them with a certain ſubſtance, from which they derive the general property of occaſionally exciting light and heat.

From this ſublunary ſtore, then, of the ſolar ſubſtance, we are to look for the emanation of ſuch virtues as belonged to the parent power. Accordingly, in plants thus prepared by the hand of Providence, are placed the ſuſtenance of animal life, and all the comforts which attend a living, feeling, and perceiving being.

For this purpoſe of cheriſhing life, it is neceſſary to diſtribute to animals, from the vegeta-

ble ſtore of nature, heat and light proportioned to their neceſſities, and apportioned to the various purpoſes for which thoſe active powers are allotted. This active principle, then, is amply provided to animals in their food; and, while the growing bodies of thoſe animals are increaſed with the neceſſary nutriment which comes from plants, at all times the vital functions are properly ſuſtained with that ſubſtance which had been originally of vegetable production.

But in order to accompliſh thoſe deſigns, this ſolar ſubſtance ſtored in the vegetable bodies muſt be reſolved from it's confined ſtate, and this muſt be performed according to ſome meaſured operation. It is here that ſo much wiſdom or contrivance is to be perceived in the operations by which animals acquire their heat, and by which bodies, naturally opake, are made to imitate the luminary of the world, and to ſupply his place for all the purpoſes of life.

Suppoſing thoſe facts to be ſufficiently evinced, let us now extend our views into the general ſyſtem of material things, in applying thoſe inveſtigated principles of action to the neceſſary operations of this world.

Here is an object highly worthy of our attention. To contemplate a ſyſtem in which, while the various purpoſes of a world ſo bountifully provided for are ſerved, there is exhibited a ſtill more intereſting proſpect; it is that of finding perfection manifeſted in each part of nature. Now, this muſt be the caſe, ſo far as in this great, in this amazingly complicated machine, we can ſee no uſeleſs matter, no inefficient form, no unappropriated action, and no ſuperfluous power. If wiſdom regulates this great machine, if order is eſtabliſhed in it's infinitely multiplied and minuteſt parts, (as we have every reaſon to ſuppoſe,) how plea-

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ſant is it to behold the manifeſtation of unbounded power conducted with benevolent deſign! What ſatisfaction to an intelligent mind to obſerve perfect order in the moſt complicated parts of nature; to trace the efficient, as well as to perceive the final cauſe; and to ſee the wiſdom in which ends have been benevolently choſen, and means effectually appointed for the accompliſhment of thoſe ends!

If the wiſdom of man is to be employed in conducting ſcience for the greateſt benefit to human nature, what end can be propoſed more effectual for producing happineſs in a thinking being, than is *the manifeſtation of a Supreme Power*, who acts with juſtice and with wiſdom? But, in finding the perfect adjuſtment of ends and means in every part of nature, we neceſſarily conclude, that there is a ſuperintending Being, whoſe power and wiſdom far exceed the comprehenſion of our ſubordinate capacity.

It is not to evince thoſe metaphyſical and moral truths that the phyſical ſyſtem of things is here inquired into; but it is the phyſical ſyſtem that I would now ſupport by metaphyſical and moral arguments; being perſuaded that thoſe different branches of ſcience, when taken in a philoſophical or general view, ſerve to throw mutual light upon each other.

It muſt not be alledged, that natural philoſophy is not concerned with final cauſes; *the contemplation of ends without means would add nothing to the value or luſtre of human wiſdom*, and FAR LESS WOULD THE KNOWLEDGE OF MEANS WITHOUT ENDS. It muſt not appear idle ſpeculation to diſcover the connection of efficient and final cauſes; for, as in ſeeing means properly adjuſted to an end, we may perceive the wiſdom of Providence, ſo, in acknowledging this wiſdom, we may find ſome means of

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trying every theory with respect to physical causes: for, every law of nature being thus necessarily conceived to be in wisdom, we have in this a rule by which to try every pretended law of nature. Now, though we may not thus positively discover what we want to know, we may negatively attain our end, in distinguishing what is erroneous.

This world consists in a system of moving bodies, actuated by a cause, and tending to an effect; that is, in a design, where ends have been contrived, and means are appointed for conducting to those ends. Here is a proposition which should be well examined; for thus may be understood the proper object of natural philosophy, which is the general science of things. Philosophy is not employed in tracing the special order of events in the progress of changing things: this is the province of the particular sciences. The proper purpose of philosophy is to see the general order that is established among the different species of events, by which the whole of nature, and the wisdom of the system, is to be perceived.

Whether we conceive this world as a mechanical machine, effecting it's purpose by the aptitude of it's various parts; or as a chemical process, changing the sensible qualities of the different bodies of which it is so properly constructed; there are necessarily required powers in order to actuate that moving system in which we live. Now, here we may perceive two different powers; gravitation, on the one hand, by which all the parts of this material system should be preserved in one united mass; and heat, on the other, by which means rest, the ultimate effect of gravitation, should be removed from this united mass containing organized living bodies. When, on the one hand, gravitation is supposed to prevail, bodies are made to form an inert mass, in which could be no system or no change.

change. When heat again prevails, bodies are dispersed as matter moving in space without a proper purpose: but by a just combination of those two different powers, we find moveable and moving bodies properly disposed in a great and connected system of things, where a circulation of matter is established, where the destruction of every individual thing is only the means employed for reproducing others of the same species, and where the natural tendency of every living thing is to preserve itself, and thus to maintain that order of things which is perceived in this world.

Without the influence of the sun, this world would remain an useless mass of inert matter; but with that influence, which is distributed so wisely in the different regions of this earth, we find motion is excited among the invisible parts of bodies, plants are made to grow, and animals are enabled to live, and find the means of pursuing their various œconomy: but, in the absence of the sun, there is required fire; this is an inferior source of light and heat; and this is a subordinate cause of action or efficiency in that mass of gravitating matter which otherwise would be inert.

Now it is not possible to explain this source of action, this necessary cause of vital motion, upon gravitating principles alone; for however we may multiply and combine attractive causes, nothing will hence result but rest, as the end or the effect. But this is not the case when we consider this mass of gravitating matter actuated by that powerful influence which appears to be derived from the sun, and which counteracts that tendency to rest inherent in the matter of this globe. Here we have two moving causes constantly operating in the system; powers variously opposing each other's action, and alternately prevailing; consequently a cause for action and re-action, without any absolute

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lute reſt. Thus thoſe oppoſing powers conſpire to form a ſyſtematic order in material things, an order of moving bodies, which neither of thoſe cauſes ſingly could have accompliſhed, and an order of life and circulation, which the conſtant action of the one power, and the continual or repeated influence of the other, certainly maintains.

It is in tracing the various ſteps in this ſyſtem of material things, (a ſyſtem ſubſervient to our ſenſe, and conducive to the enlargement of our intellect,) that natural philoſophy is employed. However, therefore, the mere chemiſt may take for granted, or as principles, fire and heat, without inquiring into their cauſe, a natural philoſopher muſt explain from whence it is that heat ſhould come on all occaſions, and how that heat is to be employed in the ſervice of the ſyſtem. Hence the laws of heat and cold, of condenſation and expanſion, of the retenſion and emiſſion of light, are equally neceſſary in the ſyſtem, and proper to be known in the philoſophy of nature, as is the meaſuring of that power by which the planets are preſerved in their orbits, or by which is eſtabliſhed the ſpherical figure of this globe.

Thus the ſyſtem of this world depends on vegetation. Vegetation, again, depends on light, as well as on heat; and both theſe requiſite conditions are procured by the influence of the ſun: but, for vegetation, light and heat are no more neceſſary than as a proper ſupply of humidity, and other requiſite conditions which are obtained from the atmoſphere. Therefore it is here neceſſary to ſee that particular law of nature on which the proſperity of plants, and the œconomy of living bodies, depend.

How much reaſon, then, have we to admire the ſyſtem of Providence! We ſee and feel with pleaſure the ends which are attained; and we never fail

fail to be gratified in proportion as we comprehend the means which are employed. The circumvolution of our globe, in a ſyſtem of planetary bodies, rendered it neceſſary that we ſhould have day and night, ſummer and winter, that is, alternate ſeaſons of light and darkneſs; the neceſſities of our animal nature required the provident ſeaſons of ſpring and autumn; and, to ſenſitive beings, the occaſional abſence of the ſun demanded a ſubordinate ſource of light and heat. Now all theſe ends appear to be attained by the proper adjuſtment of the two different ſpecies of matter, viz. of that by which bodies are expanded, and made ſoft or fluid, and of that by which they gravitate, and become hard and ſolid; of that matter by which they are naturally cold and dark; and of that, again, by which they may occaſionally become hot and luminous. It is in theſe effects that we are enabled, firſt, to read the laws of gravitation and chemical attractions; ſecondly, to form a judgment with regard to the nature of the matter which is conſidered as flowing from the ſun; and, laſtly, to ſee the various modifications of that ſolar ſubſtance by which the inert bodies of this world are actuated, contrary to the natural tendency of their gravitating matter.

LECTURE

LECTURE IX.

OF FIRE.

IT will be my endeavour, in this Lecture, to explain to you ſome other properties of that wonderful element, fire, with which all bodies in nature are imbued, ſurrounded, and penetrated, and which fills up every interval between their particles.* The ancient heathen philoſophers, when they contemplated the wonderful privilege of man in enjoying the uſe of the element of fire, perſuaded themſelves it was a privilege too great for man's eſtate in this world, and that it was originally ſtolen from heaven, and that the very theft was the crime which brought all manner of evil into the world.

Lactantius, a chriſtian father, among other arguments, to ſhew the ſuperiority of man in the creation, and the immortality of his nature, produces this, that of all the creatures known to us, man is the only one who has the command and uſe of the element of fire. He is familiar with that heavenly ſubſtance, without which there is neither light nor life, while the moſt ferocious of beaſts are alarmed by it, and fly from it. He is entruſted with a power moſt like to that of God himſelf, who has the direction of all the elements; he, therefore, has a privilege which diſtinguiſhes and ſets him above all other creatures. How dreadful would it have been if brute creatures had been entruſted with the ſame liberty, if there had been the uſe of fire where there is not the uſe of reaſon! Sorry am I to add to Lactantius, that in this, as in every other inſtance, man too often abuſes the liberty with which he is bleſſed, and perverts it to the deſtruction

* Lavoiſier Elemen. Chem. p. 185.

ſtruction of his fellow creatures. Happy will be the day when men, inſtead of flattering themſelves with the enjoyment of abſtract *rights*, ſhall conſider their reſpective *duties*, and employ themſelves in ſubduing their own paſſions, inſtead of raiſing evil and malignant diſpoſitions in others: then would all, under every form of government, enjoy real liberty, liberty to do all poſſible good, and be reſtrained from all evil; and thus there would be ſafety to the perſons and properties of every individual. Give me leave to introduce a paſſage on this ſubject from a writer whom I ſhould be happy to introduce to your acquaintance, as a real friend of liberty and freedom of thought, whoſe writings are characterized by their peculiar and unaffected candour, great good humour, and ſound reaſoning; a writer who at times, as in the following paſſage, can innocently ſport and play, and at other times employ all the maſculine energy of truth in protecting virtue, or detecting falſehood.

Speaking of liberty, he thus accoſts her: "Hail glorious liberty! the choiceſt privilege of imperial man! the prerogative by which he exerciſes his dominion over this ſublunary kingdom! thou delighteſt to dwell in this my native land, the happy Britain! whoſe ſons in former times have ſtruggled hard for thee, enduring diſtreſſes, toils, and bloody conflicts, that they might tranſmit thy bleſſings to us their children. Thou haſt ſnapped ſhort the iron rod of deſpotic ſway, broken through the enormous rule of many made for one, and taught power wherein it's real ſtrength and true glory conſiſts. Thou haſt dragged tongue-tied *ſuperſtition* at thy chariot-wheels, and bound in fetters that daſtard ſlave implicit faith, that uſed to fetter the very thoughts of men. Thou openeſt the chambers of ſcience, burſting aſunder the *ipſe dixits* that had barred up more than half the avenues. Thou

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cleareſt away the film from our eyes, that we may ſee for ourſelves; and ſtrengtheneſt our feet that we may walk without a leading-ſtring. O let us never part with the valuable inheritance our anceſtors have left us; nor, I truſt, ſhall we ever let it ſlip out of our hands: let us only beware that we *be not beguiled by falſe appearances*, nor enticed away from our goddeſs by a phantom repreſenting her likeneſs.

For there are counterfeits abroad, pretenders that aſſume thy robe and geſtures. The mimic ape, *licentiouſneſs*, imitates thine intrepid air, and confident gait. The blatent *beaſt* prophanes thy daring language with his unbridled tongue. *Conceited pertneſs* teaches the new looſened ſchool-boy, and the novel-ſtudied girl, the ſcorn of tutorage and controul. *Irreverent fanaticiſm*, ill-copier of thine eaſy carriage before ſuperiors, ruſhes with ſaucy familiarity into the council-chamber of heaven. And lion-ſkinned *free-thinking*, ſafe affector of thy bravery, inſults whom thou haſt diſarmed, ten times ſlays the ſlain, and claims to be the ſole gatherer of thy ſpoils. They range the world with a boiſterous rabble tagging at their heels; clamour, arrogance, miſrepreſentation, perverſeneſs, cavil, intemperate jeſt, loud-laughing mockery, and hoodwinked miſrule. They ſpare not things ſacred nor prophane, but pluck the grey beard of experience, tear the prelate's lawn, revile the rulers of the people, and ſpare not the Lord's anointed. The unlucky monkeys toſs all about them in confuſion, and grin at the wild work they make; they ſcatter abroad fire-brands and arrows, and cry, Are we not in ſport? They delight to trip up the unwary, or entangle the feeble in their webby filaments, and then chuckle with joy to ſee the perplexities they have occaſioned.

But thou, *genuine liberty*, offſpring of all-pro-

tecting Jove, and ſiſter of Uranian Venus, who diſpenſeth his bleſſings from her horn of plenty, thou loveſt *order* and *decency*; for thou knoweſt the world is upholden by *order*, and the bliſs of heaven maintained by *free obedience*. Therefore thou recommendeſt regularity and ſubordination to the ſons of men: thou ſtandeſt upon *law* and *ordinance* as thy baſes; *rule* and *authority* as thy ſupporters; *ſound reaſon* and *uniform prudence* as the ground thou walkeſt upon; *diſcretion* and *cautious reſerve* go before as thy harbingers; and *much-enduring charity* departeth not from thy ſide. The modeſt virgins warn thee which way to direct thy ſteps, that thou hurt not the ſimple, or cover thee with veils that thou give them not offence; for when thou walkeſt forth in the fields of ſpeculation, or ſtretcheſt thy ken to the ſources of uſeful ſcience, the weak-ſighted cannot ſuſtain thy piercing look, nor the feeble ſtand againſt the bruſh of thy ſturdy tread."*

OF THE FIRING OF GUNPOWDER.

The ſudden exploſion or *detonation* of gunpowder is the next effect of fire which we have to conſider, an effect which gave riſe to the preceding reflections. *Detonation* is a ſpeedy and rapid inflammation, which occaſions a noiſe by the inſtantaneous formation of a vacuum.

Gunpowder is a compoſition conſiſting of *ſaltpetre*, *ſulphur*, and *charcoal*; a mixture whoſe powerful effects are derived from it's great combuſtibility. The principal things to be conſidered in making of gunpowder, are the goodneſs of the ingredients, the manner of mixing them, the proportion in which they are combined, and the drying of the powder after it is made.

Saltpetre and ſulphur mixed together give no exploſion;

* Tucker's Light of Nature purſued. Vol. 2. part 3. p. 299.

explosion; sulphur and charcoal give no explosion; and though saltpetre and charcoal, when intimately united, do give an explosion, yet it is probably of far less force than what is produced from a mixture of the three ingredients.

If saltpetre be exposed to a strong heat, it melts, and becomes red-hot, and the volatile product is found to consist of fuming nitrous acid, a large quantity of vital air, some phlogisticated air, the alkali remaining behind.

When a combustible substance and saltpetre be brought into contact, either of them being previously heated red-hot, the body is heated with great rapidity; no doubt from the vital air which is disengaged by the heat, as the experiment succeeds in vacuo, and also when the bodies are surrounded by an aeriform fluid incapable of maintaining combustion.

The rapid combustion effected by nitre, when it is performed by a successive burning of the parts of a body, is called *deflagration*; when it is performed in so short a time as to be nearly instantaneous, it is called, as was observed before, *detonation*.

It is remarkable in this experiment, that the combustion is maintained by the vital air combined with the nitre: it is this property of the saltpetre that has been applied to the production of gunpowder.

This destructive powder is composed of 75 parts, by weight, of nitre, 9 ½ of sulphur, and 15 ½ of charcoal; these substances are intimately blended together by being triturated from ten to fifteen hours in wooden mortars with pestles of the same substance; a small quantity of water is added from time to time to moisten the mixture; when the whole of the fluid is evaporated, so that the powder will not soil an earthen plate, it is carried to be granulated, which is effected by passing it through

ſieves whoſe perforations are of various ſizes; and theſe being ſhaken or rolled in a barrel, take a rounded form from their friction againſt each other.

From the experiments of Meſſrs. Beaumé and D'arcy, it is clear, 1. That good gunpowder cannot be made without ſulphur. 2. That charcoal is indiſpenſably neceſſary. 3. That the quality of gunpowder depends, *cæteris paribus*, upon the care with which the materials are blended together. 4. That the effect of gunpowder is greater when ſimply dried, than when it is granulated.

All the phenomena which attend the inflammation of gunpowder, depend entirely on it's great combuſtibility. The intimate mixture which has ſo great an influence on the force of gunpowder, is the principal cauſe of it's effects; the nitre is equally diſperſed among all the particles of very combuſtible matter; as the quantity of nitre is greateſt, each particle of ſulphur and charcoal is ſurrounded, and as it were covered with nitre. Nitre affords, by the application of heat, great quantities of vital air. The ſame thing therefore happens in this combuſtion, as is obſerved, when a combuſtible body is plunged into a veſſel filled with vital air; that is to ſay, it is burned with greater vivacity, and in leſs time, than in common atmoſpheric air. It follows therefore, that the ſulphur and the charcoal muſt be burned in an inſtant, being plunged in an atmoſphere of vital air. Hence the rapid decompoſition of nitre, and the rapid inflammation of the powder. This, together with it's taking place in cloſe veſſels, may in a great degree account for the violent force with which it explodes, and drives every obſtacle before it.

The quantity of fire diſengaged at the moment of detonation contributes conſiderably to the expanſive effect of gunpowder. Although fire penetrates

trates through the pores of every ſubſtance in nature, it can only do ſo progreſſively, and in a given time: hence when the quantity diſengaged at once is too large to get through the pores of the ſurrounding bodies, it muſt neceſſarily act in the ſame way with ordinary elaſtic fluids. This muſt at leaſt take place in part when gunpowder is ſet on fire in a cannon; for although the metal is permeable to fire, the quantity inſtantaneouſly diſengaged is too large to find it's way through it's pores; it muſt therefore make an effort to eſcape on every ſide; and as the ſurrounding reſiſtance, except at the muzzle, is too great to be overcome, this effort is employed in expelling the bullet.

Fire produces a ſecond effect from it's expanſive force, which cauſes the aerial fluids diſengaged at the moment of deflagration to expand with a degree of force proportioned to the temperature. It is probable alſo that a quantity of inflammable air is diſengaged at the inſtant of deflagration, which expanding contributes to the force of the exploſion. You will eaſily conceive how greatly this circumſtance muſt increaſe the effect of the powder, if you conſider that a pint of inflammable air weighs only one grain and two thirds; hence a ſmall quantity in weight muſt occupy a very large ſpace, and muſt exert a prodigious expanſive force in paſſing from a liquid to an aeriform ſtate of exiſtence. Laſtly, a portion of undecompoſed water is reduced to vapour during the deflagration of gunpowder; and as water, in vapour, occupies 17 or 1800 times more ſpace than in it's liquid ſtate, this circumſtance muſt alſo contribute largely to the exploſive force of the powder.

The permanently elaſtic fluid generated in the firing of gunpowder, is calculated by Mr. Robins to be about 244, if the bulk of the powder be 1; and that the heat generated at the time of the ex-

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plosion, occasions the rarified air thus produced to occupy about 1000 times the space of the gunpowder. This pressure may therefore be called equal to 1000 atmospheres, or 6 tons, upon a square inch.

We are told of a singular circumstance which attends the firing of gunpowder; that, although it seems to generate it's own air, and expand by the force of it's own materials, a seed of the common thistle with it's down, or any other light body, suspended near fired gunpowder, is always driven *inwards* towards the powder before it is driven *off* by the explosion.

The effects of this mixture are nothing in comparison with those of another, called *fulminating powder;* which is made by rubbing together in a hot marble mortar, with a wooden pestle, three parts by weight of nitre, two of mild vegetable alkali, and one of flowers of sulphur, till the whole is accurately mixed. If a drachm of this powder be exposed to a gentle heat in an iron ladle, it melts, and soon after produces a detonation as loud as the report of a cannon. This phenomenon is the more extraordinary, as the effect thereof is produced without inclosing the powder in any instrument. It is explained by observing, 1. That this experiment only succeeds by gradually heating the mixture so as to melt it. 2. That if fulminating powder be thrown on ignited charcoal, it only detonates like nitre, but with very little noise. 3. That a mixture of liver of sulphur with nitre, in proportion of one part of the former and two of the latter, fulminates with more rapidity, and produces as loud a report as the mixture of sulphur, nitre, and alkali. Hence it appears, that when fulminating powder is heated, liver of sulphur is formed before the detonation takes place; and this will serve to account for the whole appearance.

Inflammable air is formed from the liver of sulphur,

ſulphur, while the ſalt gives vital air; theſe two are capable of producing a ſtrong inflammation, and are ſet on fire by a portion of the ſulphur; but as the thick fluid they are obliged to paſs through preſents a conſiderable obſtacle, and as the whole takes fire at the ſame inſtant, they ſtrike the air with ſuch rapidity, that it reſiſts in the ſame manner as the chamber of a muſket reſiſts the expanſion of gunpowder. A proof of this is obſervable in the effect the fulminating powder has on the bottom of the ladle in which it explodes. The bottom of this is bulged outwards, and the ſides are bent inwards, in the ſame manner as if it had been acted on by a force directed perpendicularly downwards, and laterally inwards.

The moſt ſurprizing inſtance of chemical detonation is that by the combination of volatile alkali with ſilver; gunpowder, and fulminating gold, are not to be compared with this new product; as the former requires ignition, and the latter a ſenſible degree of heat, to make it fulminate. But the ſlighteſt agitation or friction is ſufficient to cauſe the fulminating ſilver to explode. *When it is once obtained, it can no longer be iouched.* The falling of a few atoms of this preparation from a ſmall height, produced the detonation: a drop of water falling on it had the ſame effect. No attempt, therefore, can be made to incloſe it in a bottle, but it muſt be let alone in the capſule, wherein, by evaporation, it obtained this terrible property. To make this experiment with ſafety, no greater quantity than a grain of ſilver ſhould be uſed, and the laſt deſiccation ſhould be made in a metallic veſſel, and the face of the operator defended by a maſk, with holes for the eyes defended by ſtrong glaſs. The exploſion, as in the former inſtances, depends upon the ſudden formation of aerial fluids.

OF SOLUTION.

This is another operation of fire, which is connected more or leſs with every phenomenon in nature. When the parts of a ſolid body, as common ſalt or ſugar, are ſo united to a fluid as water, that they compoſe with it an apparently homogeneous fluid, remain ſuſpended in it, and do not deſtroy it's tranſparency, the ſolid body is ſaid to be *diſſolved* in the fluid; the operation is called *ſolution*, the fluid is called the *ſolvent*, or more commonly *the menſtruum*; the compound reſulting from the union of the fluid and the body, is called a ſolution of this or that body, in this or that menſtruum.

In chemiſtry, the terms *ſolution* and *diſſolution* have long been confounded, and have very improperly been indiſcriminately employed for expreſſing both the diviſion of the particles of *a ſalt in a fluid*, ſuch as water, and the diviſion of metals in an acid. A few reflections on the effect of theſe two operations, will ſoon convince you, that they ought not to be confounded together.

In the ſolution of ſalts, the ſaline particles are only ſeparated from each other, but neither the ſalt nor the water are at all decompoſed; we are able to recover both the one and the other in the ſame quantity as before the operation. The ſame thing takes place in the ſolution of reſins in alcohol. On the contrary, during metallic diſſolutions, a decompoſition either of the acid, or of the water which dilutes, always takes place; the metal combines with the acidifying principle, is changed into a calx, and an elaſtic fluid is diſengaged, ſo that none of the ſubſtances employed remain, after the operation, in the ſame ſtate as before. This article is confined to the conſideration of ſolution.

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The neceſſary conditions for ſolution, are a certain accommodation of the parts of the ſolvent to thoſe of the ſolvend, and a proper degree of motion or agitation to apply the parts of the one to the parts of the other: of this motion fire is the general cauſe. You may illuſtrate this by an eaſy experiment: if you place a ball of clay in cold water, it remains at reſt, and the fluid continues pure as before; but if you ſet this water over the fire till it boils, the clay is ſoon diffuſed through it, and the whole is turbid as long as the parts of the water are agitated by the fire; but when the water grows cold, the clay ſubſides to the bottom, and leaves the water clear. The parts of the clay being ſpecifically heavier than thoſe of the water, ought to ſubſide in them; but this is prevented by a motion from the parts of fire. If they are properly agitated, they are ſuſpended in the fluid; and if they are ſuſpended, it follows that they are agitated. From extraordinary caſes we are to learn what happens in thoſe that are ordinary. It is here evident, that fire, by it's motion, ſeparates and ſuſpends the parts of a ſolid body in a fluid.

Where the motion of fire is violent, the ſolution is quickly accompliſhed, and a very large quantity of the ſolvend is ſuſtained in the fluid medium. Therefore, in all ordinary caſes, where the ſolution is ſlow and gradual, and the quantity ſuſpended is but inconſiderable, the ſame effect is produced by that imperceptible inteſtine motion, which conſtantly agitates the atmoſphere and all things therein. The conſtant exhalations from the ſurface of water, ſhew that there muſt be a perpetual motion of it's particles; and moſt menſtruums are rendered ſuch, and derive all their activity from fire, which co-operates with, and gives them their proper effect.

All ſalts may be liquified by fire alone, but with different

different degrees of temperature. Some of theſe, as the acetated pot-aſh and ſoda, liquify with a moderate heat; whilſt others, as vitriol of pot-aſh, lime, &c. require the ſtrongeſt fires that can be made. This liquifaction of ſalts by *fire* produces exactly the ſame phenomena as were explained to you when I treated of the liquifaction of ice. Fire is employed and fixed during the melting of the ſalt, but is *diſengaged* when the ſalt coagulates. *Theſe are general phenomena which occur univerſally during the paſſage of every ſpecies of ſubſtance, from a ſolid to a fluid ſtate, and from fluid to ſolid.*

The phenomena which ariſe in the ſolution by fire alone, are always more or leſs conjoined with thoſe that take place during ſolutions in water: and the nature of the ſolution of a ſalt by fire, determines the nature of a ſolution by water. If, for inſtance, a ſalt be difficultly ſoluble in water, and readily by fire, it evidently follows that it will be eaſily ſolved in hot water, though not in cold. But if it be ſcarce ſoluble either in water or by fire, the difference between hot and cold water will be very inconſiderable. Theſe conſiderations ſhew, that there is a neceſſary relation between the ſolubility of ſalt in water, and the degree of temperature at which the ſame ſalt liquifies by fire, unaſſiſted by water; and that the difference of ſolubility in hot or cold water, is ſo much greater in proportion to it's ready ſolution in fire, or in proportion to it's ſuſceptibility of liquifaction in a low degree of temperature. Hence, the reaſon why ſalts are more rapidly ſoluble in hot than in cold water, is perfectly evident; in all ſolutions of ſalts fire is employed; when fire is furniſhed intermediately from the ſurrounding bodies, it can only arrive ſlowly to the ſalt; but when the requiſite fire exiſts, ready to act with the water of ſolution, it operates directly on the ſalt.

That

That the power of ſolution is not in the water, is evident from the following experiment: Let ſome water boil over the fire in a glaſs veſſel, caſt into this ſea-ſalt by a little at a time, and you will find, that after a large quantity has been diſſolved, the water will be as tranſparent as before; which ſhews the ſolution to be perfect. Then let the veſſel be removed from the fire, and as the water begins to cool, ſome ſalt will fall to the bottom; as it approaches nearer to the temperature of the air, more and more of the ſalt will be depoſited; and hence we argue, that as fire keeps the larger quantity ſuſpended, what remains ſuſpended at laſt, is ſupported by the ordinary effect of the remaining heat; and that if water could be found without fire, it would be without the power of ſolution. And indeed this power never fails to leave it at a certain period, as when the water is frozen into ice; becauſe a ſolid maſs cannot act as a ſolvent. The ſame medium that gives it fluidity, makes it a menſtruum, and it's diſſolving power increaſes with it's heat. Water is therefore a ſolvent only as far as it is enabled to be ſo by fire, and conſequently, in ſuch ſolutions, not water but fire is the agent.

If you take an ounce of common ſalt, and throw it into a quart of water, in a very little time, eſpecially if the water be ſtirred, the ſalt will diſappear, being uniformly diſperſed through the whole body of the water. If you add another ounce of ſalt, that will alſo be diſſolved, but not ſo ſpeedily as the firſt. By this power of ſolution you may add ſo much ſalt to the water, that it will not diſſolve one particle more; the water in this ſtate is properly enough ſaid to be *ſaturated*. This however does not prevent a certain quantity of another ſalt being diſſolved, and after that perhaps a third or a fourth.

OF CRYSTALLIZATION.

In this proceſs, the integrant parts of a ſolid body are ſeparated from each other by the intervention of a fluid, coaleſce, and reproduce a ſolid maſs.

When the particles of the body are only ſeparated by fire, and thereby retained in a liquid ſtate, all that is neceſſary to make it cryſtallize, is to remove a part of the fire, which is lodged between it's particles, in other words, to cool it. If this refrigeration be ſlow, and the body be at the ſame time left at reſt, it's particles aſſume a regular arrangement, and cryſtallization, properly ſo called, takes place. But if the refrigeration be made rapidly, or if the liquor be agitated at the moment of it's paſſage to the concrete ſtate, the cryſtallization is irregular and confuſed.

The ſame phenomena occur with watery ſolutions, or rather in thoſe made partly in water and partly by fire. So long as there is a ſufficiency of fire and water to keep the particles of a body aſunder, the ſalt remains in a fluid ſtate; but when theſe are not preſent in ſufficient quantity, the ſalt recovers it's concrete form, and the cryſtals produced are more regular, in proportion as the evaporation is ſlower and undiſturbed.

All the phenomena we formerly mentioned as taking place during the ſolution of ſalts, concur in a contrary ſenſe during their cryſtallization. Fire is diſengaged at the inſtant of their aſſuming a ſolid ſtate: a further proof of the agency of fire. Hence to make ſalts cryſtallize, which readily liquify by means of fire, it is not ſufficient to evaporate the water, but the fire united with them muſt alſo be removed. Saltpetre, alum, &c. &c. are inſtances in which to make the ſalts cryſtallize, refrigeration muſt be added to evaporation. On the other hand, ſuch ſalts as require but little fire to be

kept

kept in ſolution, and which from that circumſtance are equally ſoluble in cold as warm water, are cryſtallizable by evaporation alone, and even recover their ſtate in boiling water. The ſeparating matter being removed, the ſalts aſſume a form natural to their ſtate, or, in other words, cryſtallize.

OF CLARIFICATION.

This is effected either by ſeparating the groſſer particles, and heterogeneous matters, from liquors, ſo as to leave them clear and tranſparent; or by rediſſolving the parts, which are tending to a precipitation, that they may be equally diffuſed, ſo as to become inviſible. When the precipitation is occaſioned by that contraction which proceeds from cold, heat is the natural remedy. If wine is grown thick and turbid with cold, a gentle warmth will promote a ſolution, and make it clear again. Urine, when exceedingly turbid, may be reſtored to it's former tranſparency, by applying an heat equal to that of the human body. Some bodies are purified when the fire carries off the baſer part, and leaves the finer: thus gold and ſilver are purified in the furnace. Other matters are purified by the fire carrying off the finer part, and leaving thoſe which are too groſs to aſcend: thus ſea-water is made freſh by diſtillation. But the effect of fire is never more manifeſt in this clarifying work, than when it raiſes a ſcum to the top of a boiling liquor. Fire purifies in many other ways known to chemiſt-painters, dyers, and other manufactories. The word *purity* is beſt accounted for by deriving is from πυρ, fire, becauſe fire is the grand agent which purifies all things.

OF ODOURS.

Odours are ſo generally excited and even generated by the action of fire on various ſubſtances,

that

that ſome of them ſeem to owe their exiſtence to it. The powder of brimſtone is inodourous when cold. But nothing has a more pungent ſmell than the vapour thereof when opened and diffuſed by fire. Vinegar has but little ſmell in the common temperature of the atmoſphere, but when heated, it is exceeding ſtrong and penetrating. Little or no ſmell is perceived in the freſh bone of an animal; but if it be laid on the fire, the ſmell will be diffuſed through the whole houſe. It is the ſame with feathers, which are intolerably fœtid when ſcorched in the fire. *This offenſive ſmell is a criterion of animal ſubſtances*, as diſtinguiſhed from *vegetable*, and has been uſed to determine to which of theſe kingdoms the corals and coralline bodies belong, that are taken out of the ſea. All the odours ariſing from putrifying bodies depend much upon the action of heat; and it appears to be the deſign of Providence, that when carcaſes are moſt ſubject to putrify, and become noxious with the heats of ſummer, there is a generation of flies ſwarming in the air, ready to remove all offences as faſt as poſſible, by a voracious breed of maggots. In extreme cold, there is no ſmell from dead bodies, becauſe there is no putrifaction. As the moſt fragrant liquors when frozen emit no ſmell, ſo the carcaſes of men and beaſts which have died upon that vaſt ridge of mountains, the Andes, in South-America, are reported to have been found untainted for many years.

OF THE DIFFERENT METHODS OF EXCITING AND COLLECTING FIRE.

There are three methods of exciting fire: 1ſt. By the colliſion or friction of ſolid bodies. 2. By fermentation or efferveſcence. 3. By uniting the ſolar rays.

Colliſion

Collifion or friction of folid bodies, is the means moft generally ufed for exciting the action of fire. The vacuities of all folid bodies are replete with fire, fo that it is impoffible to agitate or feparate their parts fwiftly, without giving the fame rapid motion to the element contained within them. When a piece of hardened fteel is ftruck with a flint, fome particles of the metal are fcraped away from the mafs, and fo violent is the fire which follows the ftroke, that it melts and vitrifies them. If the fragments of fteel are catched upon paper, and viewed with a microfcope, you will find moft of them perfect fpherules, and very highly polifhed. Their fphericity demonftrates they have been in a fluid ftate, and the polifh upon their furface fhews them to be vitrified; the fire being difengaged with violence, difpofes the particles of the fubftance to combine with the vital air, while this air accelerates the combuftion. The whole of the heat produced, is not afforded by the body itfelf, becaufe in proportion as the interior fire is difengaged, the external air acts upon the body, and gives out fire.

It is not, as I have already obferved to you, every *agitation*, that raifes heat in bodies. *A bell, or other fonorous body*, may receive a *ftroke*, by which all the particles of the metal are thrown into a *vibratory* motion, which continues for fome time, but is not attended with any heat. The following conditions feem to be requifite: 1ft. That one body fhould be in contact with another. 2. That it fhould move fwiftly over it: which conditions are implied in the term *attrition*. Thefe effects are more or lefs rapid and violent, according to the nature of the fubftance, and the degree and duration of the collifion, or the degree of friction. Friction is increafed by preffure and velocity; therefore the clofer

ſer the contact, and the ſwifter the motion, the more vigorous is the fire.

If the irons at the axis of a coach-wheel are applied to each other, without the interpoſition of ſome unctuous matter to keep them from immediate contact, they will become ſo hot, when the carriage runs ſwiftly along, as to ſet the wood on fire; and the fore wheels being ſmalleſt, and making more revolutions, will be moſt in danger. The ſame will happen to mill-work, or any other machinery, if the neceſſary precautions are neglected. It is no uncommon practice with a blackſmith to uſe a plate of iron as an extemporaneous tinder-box; for it may be hammered on an anvil, till it becomes red-hot, and will fire a match of brimſtone. A ſtrong man who ſtrikes quick, and keeps turning the iron, ſo that both ſides may be equally expoſed to the force of the hammer, will perform this in leſs time, than would be expected. If in the coldeſt ſeaſon you lay one denſe iron plate on another, and preſs the upper one, by a weight, on the lower one, and then rub the one over the other, by reciprocal motions they will firſt grow warm, and at length ſo hot, as in a ſhort time to emit ſparks, and at laſt grow red-hot, as if taken out of a vehement fire.

It is not neceſſary that the ſubſtance ſhould be very hard; a cord rubbed backwards and forwards ſwiftly againſt a poſt or a tree will take fire; a ſtick of wood preſſed againſt another which is turned ſwiftly about in a lathe, will ſoon make it turn black, and emit ſmoke. Even the palms of your hands, if you rub them briſkly together, when they are dry, will ſmell as if they were ſcorched. The method of exciting fire by rubbing two ſticks of wood together, was anciently practiſed by country people, and is ſtill retained in ſome parts of the world. The manner is exactly deſcribed in Captain

tain Cook's voyage. The inhabitants of New Holland are there ſaid to produce fire with great facility, and ſpread it in a wonderful manner. To produce it, they take two pieces of *ſoft* dry wood; one is a ſtick about eight or nine inches long, the other piece is flat. The ſtick they ſhape into an obtuſe point at one end, and preſſing it upon the other, turn it nimbly by holding it between both their hands, as we do a chocolate mill, often ſhifting their hands up and down, and then moving them down upon it to increaſe the preſſure as much as poſſible. By this method they get fire in leſs than two minutes, and from the ſmalleſt ſpark they increaſe it with great ſpeed and dexterity. This is the fact, to which a reflection is added, which calls for indignation; the more ſo, as it has been adopted and propagated for the purpoſes of atheiſm and infidelity, by ſome writers of a neighbouring nation. "There are few things (ſays the editor of the voyage) in the hiſtory of mankind more extraordinary than the diſcovery and application of fire. It will be ſcarcely diſputed, that the manner of producing it, whether by colliſion or attrition, was diſcovered by *chance*. Theſe circumſtances conſidered, how men became ſufficiently familiar with it, to render it uſeful, ſeems to be a problem difficult to ſolve." The following obſervation by the Rev. Mr. William Jones, on this paſſage, is well worth your attention; indeed I know of ſcarce any man's writings, which can be more ſafely recommended to you; they are replete with original obſervations, and are founded upon the ſoundeſt and beſt principles both of reaſon and revelation. On the foregoing quotation he obſerves, "that theſe reflections might well have paſſed for the ſpeculation of a New Hollander; and that we need not be ſurprized to find a ſimilar one in the Faſti of Ovid, an heathen writer. But, that

people in a christian, civilized, philosophical country, whom *Divine Providence* has blessed with a knowledge of the true origin of mankind, and their earliest history, should condescend *to such poor and weak conjectures*, is a symptom of present infidelity, and approaching barbarism. The first family, placed by the Creator upon this earth, offered sacrifices, which being an article of religious duty, they were certainly possessed of the means of performing it, and consequently of the knowledge and use of fire, without which it could not be practised. The Bible account is natural, and more agreeable to the goodness of God, and the dignity of the human species, than to suppose, on the principles of a *wild* and *savage* philosophy, that men were left ignorant of an element designed for their accommodation and support.

"To interdict a man from the use of fire and water, was accounted the same, in effect, as to send him out of life; so that if men, upon the original terms of their creation, were thus interdicted by the Creator himself, as the heathen mythology supposed them to be, they were sent into life upon such terms as others were sent out of it. If you admit any one such gloomy supposition, where shall we stop? If mankind were left destitute of the knowledge of fire, perhaps they were left without food, without cloathing, without reason, and in a worse condition than the beasts, who are born with the proper knowledge of life: but man receives his knowledge by education; therefore he who taught the beasts by instinct, taught man by information."

OF FERMENTATION AND EFFERVESCENCE.

These seldom take place without exciting heat, which is sometimes so great as to break out into

into actual flame. Pour an acid on an alkali, and an effervescence is excited productive of heat; pour water upon oil of vitriol, and you will produce a great degree of heat, often sufficient to break the vessel, if it be composed of fragil matter; pour upon oil a highly concentrated acid, the fermentation will be great, and the fire disengaged will often burst into actual flame: a mixture of water and spirit of wine will also manifest heat. These effects are produced by the friction and collision of the particles of the different substances, by which *fire* is expelled, and the space it occupied is filled up by the mutual penetration of the fluids. If the heat produced be very great, the ambient air is decomposed, and an inflammation ensues. The penetration of the substances is easily proved, for their bulk is less after the mixture than before. If you mix a pint of water with a pint of spirit of wine, the mixture will not fill a quart, which clearly evinces the mutual penetration of the substances. In fermentation, and every operation which changes the nature of bodies, fire is disengaged, to answer the purpose of the new compound: hence in chemical operations, cold is sometimes produced, and sometimes heat.

Putrifaction is also a species of fermentation. In putrifaction bodies are heated by the fire which is then disengaged, while the bodies are combined with particles from vital air.

If a large quantity of hay be laid together in too moist a state, it will by degrees take fire: this is easily accounted for, when you consider how much fire is left, which should have been carried off in vapour; this moisture and fire are expelled by the pressure of the hay; the fire being excited and unable to escape as fast as it arises through the pores of the incumbent matter, the agitation and attrition are so increased, that it breaks out into actual

 flame,

flame, and consumes the substance. So intense is the heat when a large stack of hay is on fire, that the substance of the hay is often turned into glass.

The third means of exciting the action of fire is by the *rays of the sun.* These rays warm all substances which are exposed to their action; they insinuate themselves among the particles of the body, and adding to the quantity of fire it already contains, heat is produced. The effect of these rays, when collected by mirrors, or by lenses, into a focus, is very great. If a great number of plane mirrors receive the rays of the sun, and these rays are so directed as to fall upon the same substance, the body will be considerably heated, and more so in proportion to the number of rays that fall on the body. So long as the rays preserve their parallelism, but little heat arises from them; but when they are thrown together in various directions, and return upon themselves, either by the action of air, or by attrition, or by the refractions and reflections of burning-glasses, they work together with an expansive force, and never fail to affect us with a sense of heat.

Present a concave mirror to the rays of the sun, so that the plane of the mirror may be as nearly as possible perpendicular to the incident rays before the mirror, a bright cone of light will be formed; the reason of which I shall explain in the Lecture on Catoptrics. If you place any substance at the apex of this cone, it will be quickly melted, burnt, calcined, or vitrified, according to it's nature.

In the same manner, if you expose a convex lens to the sun, so that it's axis, when prolonged, may be nearly parallel to the incident rays, a cone will be formed behind the lens, in the apex of which the same effect will be produced as with the concave mirror.

The solar light will act as the most violent fire, even

even in vacuo: it will act alſo in the ſame manner on the top of the coldeſt mountains. Nay, Mr. de Sauſſure thought it more powerful on the top of the mountain than on the plain below. Thus we find the ſolar light producing heat where there is ſcarce any other ſubſtance preſent, that we know of, but the light itſelf, and the body to be acted upon.

From theſe experiments we may conclude, that by whatſoever means the ſolar rays are united, they produce heat, which is more active in proportion as a greater number are collected together in the ſmalleſt ſpace. The activity at the focus of a lens is relative, not only to the number of rays collected together in a given ſpace, and conſequently to it's ſurface or diameter, but alſo to the manner in which they are collected; for if between the lens and it's focus, and at about two thirds the length of the axis of the luminous cone from the lens, you place another ſmaller convex lens, this lens will increaſe the convergence of the rays, and thereby augment their activity, although there may be fewer rays collected together; for many of them are intercepted by the ſolid parts of the lens. From whence it follows, that the focus is more powerful in proportion as the rays collected together form amongſt themſelves more obtuſe angles.

The effects produced by a convex lens depend on it's tranſparency and figure; every tranſparent ſubſtance of the ſame figure will produce the ſame effects: thus, a burning lens may be formed of ice, or even a bottle of water. In the ſame manner, the effects of concave mirrors depend only on the poliſh of their ſurface and the figure, ſo that they may be made of plaiſter of Paris, paper, &c. The parallel rays of the ſun might go on for ever, and give little or no ſenſation of heat; but as ſoon as they are turned upon each other by the refractions

of a convex lens, or the reflections of a concave mirror, heat is the immediate consequence: how intense soever the fire at the focus may be, it vanishes the instant the glass is removed. The solar rays alone do not produce heat; for when they are acting on any substance, you may place your finger within a few inches of the largest burning lenses with as much impunity as if you were 20 feet distant.

We may conclude from these experiments, that where light proceeds in a considerable quantity from a point, diverging as the radii of a circle from it's center, there a considerable degree of heat will be found to exist, if an opake body with no great reflective power is placed at, or very near the point. The action of the light may, in this case, be considered as the ultimate cause of the heat.

If the point from which the rays are emitted be in a transparent medium, as air or water, that medium without the presence of an opake body will not be heated: another cause therefore of heat is the resistance of the parts of the body on which the light falls.

If a body capable of reflecting light very copiously be brought near the lucid point, it will not be heated; a penetration therefore of light into the substance, and a considerable degree of resistance on the part of the body to the action of light, are requisite to the production of heat; consequently those bodies will conceive the greatest degree, into whose substance light can penetrate best, i. e. which have the least reflective power, and which most strongly resist it's action, as is evidently the case with black and solid substances.

Archimedes is the first we read of who used burning-glasses of considerable power. It is related of him that he set fire to the ships of Marcellus by means of a burning-glass, composed of small square mirrors, moving every way upon hinges, which

when

when placed in the ſun's rays, directed them upon the Roman fleet ſo as to reduce it to aſhes at the diſtance of a bow ſhot.* Many of the diſcoveries of this wonderful man have appeared ſo much above the reach of man, that among the learned it has been found more eaſy to call them in doubt, than to inveſtigate the means whereby he had acquired them; and ſome have boldly denied what they did not underſtand. This was the caſe with his mirror, the poſſibility of producing ſuch effects being denied, till it had been in ſome degree realized by Father Kircher and Mr. Buffon; the latter availing himſelf of the contrivance of Archimedes, formed a burning-glaſs of 168 ſmall plain mirrors, which produced ſo conſiderable a degree of heat, as to ſet wood in flames at the diſtance of two hundred and nine feet, melt lead at 120, and ſilver at 50.

The lens of M. de Tſchirnhauſen, which was between three and four feet diameter, and whoſe focus was rendered more vivid by a ſecond lens, vitrified tiles, ſlates, pumice ſtones, &c. in a moment; pitch and all reſins were melted even under water; the aſhes of vegetables, wood, and other matters, were tranſmuted by it into glaſs; indeed it either melted, calcined, or diſſipated into ſmoke, every thing applied to it's focus.

Mr. Parker, of Fleet-ſtreet, made a lens of 3 feet diameter of flint glaſs, which, when in it's frame, expoſed a ſurface of 2 feet 8½ inches to the ſolar rays; it had a ſmall lens fitted to it, to converge the rays and heighten the effect. The experiments made with this lens are too numerous to be related here; it will be only neceſſary to obſerve, that they were made with much greater accuracy than any made by other glaſſes. The following TABLE will give you a general idea of it's effects.

* Duten's Enquiry into the Origin of the Diſcoveries attributed to the Moderns.

TABLE

OF

Subſtances Fuſed, with their Weight and Time of Fuſion.

	Weight in grains.	Time in ſeconds.
Gold, pure - - -	20	4
Silver, do. - - -	20	3
Copper, do. - - -	33	20
Platina, do. - - -	10	3
Nickell - - -	16	3
Bar iron, a cube - -	10	12
Caſt iron, a cube - -	10	3
Steel, a cube - - -	10	12
Scoria of wrought iron - -	12	2
Kearſh - - -	10	3
Cauk, or terra ponderoſa -	10	7
A topaz, or chryſolite - -	3	45
An oriental emerald - -	2	25
Chryſtal pebble - -	7	6
White agate - - -	10	30
Flint, oriental - - -	10	30
Rough cornelian - -	10	75
Jaſper - - -	10	25
Onyx - - - -	10	20
Garnet - - -	10	17
White rhomboidal ſpar -	10	60
Zeolites - - -	10	23
Rotten ſtone - - -	10	80
Common ſlate - -	10	2
Aſbeſtos - - -	10	10
Common lime-ſtone - -	10	55
Pumice-ſtone - -	10	24
Lava - - - -	10	7
Volcanic clay - - -	10	60
Corniſh moor-ſtone - -	10	60

This

This (*fig.* 8, *pl.* 5,) reprefents the ufual mode of mounting large burning lenfes; the large lens is placed in a frame AB, the fmaller lens in the frame CD parallel thereto, and connected to the larger one by the ribs of wood a, b, c, d, e, f. H is the apparatus for fupporting the fubftance that is to be expofed to the rays of the fun. The whole is fupported on a femicircle E F G, by which the lenfes may be placed in a proper direction to receive the rays of the fun. The femicircle is fuftained by a ftrong pillar and claw.

OF THE METHODS OF AUGMENTING OR DIMINISHING THE ACTION OF FIRE.

The *firft* method is to increafe the quantity of fuel; the *fecond*, to concentrate this action, and prevent it's being diffipated in too great a fpace; *thirdly*, to direct the action of the fire to one place; *fourthly*, to blow the fire with vital air.

The *firft method* is familiar to every one. You all know that by adding fuel a fire may be increafed: the quantity of fuel laid on the fire, muft, however, always be proportioned to it's bulk and degree of inflammability. No fubftance can be inflamed without vital air, and the developement of phlogifton; and this only takes place at a certain degree of heat. If the fire be fmall, and the fubftance large and damp, the fire is extinguifhed before a fufficient heat can be communicated to the fubftance. In the fame manner a candle is extinguifhed by inverting it, the tallow which runs upon the wick not being fufficiently heated for inflammation.

The *fecond method* is ufed by artifts and chemifts, by means of their furnaces, which they endeavour fo to conftruct, that the fire contained therein may become a center of activity, whofe rays ftriking

ſtriking the top of the furnace are thence reverberaed, and concentrated ſo as to act with greater force.

The *third method* is put in practice alſo by a variety of artiſts, who concentrate and direct the flame by means of the blow-pipe or bellows: the flame thus directed is of force ſufficient to melt glaſs, enamel, and metals; for by this means, the fluid proper for combuſtion is introduced into the flame, and a great heat excited at the place required. Thus the effect of the moſt violent heat of furnaces may be produced by the flame of a candle or lamp, urged upon a ſmall particle of any ſubſtance by the blow-pipe.

The *fourth method* conſiſts in animating the fire with vital air. Mr. Lavoiſier has made many curious experiments with fire thus animated, and has hardly found any ſubſtance which did not yield to it's violence; it exceeded even any thing effected by burning-glaſſes or mirrors. For, in his firſt attempt, the intenſity of the heat produced was ſo great as to melt with eaſe a ſmall quantity of crude platina; it ſoldered rubies together without injuring their colour, or affecting their weight; emeralds, chryſolite, and garnet, were almoſt inſtantly melted into an opake-coloured glaſs. Here it may be worth obſerving, that among precious ſtones the diamond preſents a property peculiar to itſelf; it burns in the ſame manner with combuſtible bodies, and is entirely diſſipated.

I ſhall now lay before you ſome opinions on this intereſting element, which could not be introduced with eaſe in the body of the preceding Lectures, leaving you to compare them when at leiſure with the facts you already know, and the hypotheſes you have juſt examined.

The authors of the Encyclopædia Britannica agree with Mr. Lavoiſier in reprobating the uſe of the word *heat* inſtead of *fire*, becauſe heat is not a fluid but

but a modification of a fluid; and that in this view of things, it can neither be abſorbed nor attracted, neither can any body have a greater capacity for it than another, except in proportion to it's bulk, which allows a larger quantity of fire to enter, and to aſſume that particular motion which conſtitutes heat. As heat is evidently occaſioned by the rays of the ſun when concentrated, and alſo by the concentration of the electric fluid; if fire therefore be the cauſe of heat, (as is clearly proved, in the following Lectures,) we are certainly entitled to conclude, that the light of the ſun, and electricity, are modifications or component parts of elementary fire. When bodies are heated, they expand in every direction; therefore fire, when in a riſing ſtate, acts as *from a center to a circumference*; when in a deſcending ſtate, or growing colder, it acts *from a circumference to a center.*

It has been already ſhewn, by undeniable experiments, that fire is the cauſe of fluidity: when the expanſive action of this element is confined within the ſurface of any body, to preſerve it in a particular ſtate, it may be called *latent fire*; becauſe it does not extend beyond the ſurface, and cannot affect the thermometer, or have it's exiſtence manifeſted to us by the ſenſe of feeling. But when this expanſive action is transferred from the internal parts of the ſubſtance to the ſurface, it then affects the thermometer.

This is by ſome writers called the converſion of *latent* into *ſenſible heat*; by others the alteration of the *capacity*: whatever name we give the effect, the cauſe remains the ſame, the oppoſite actions of the ſame fluid; the expanſive action in ſome caſes counteracting or overcoming the condenſing one, and *vice verſa.*

In many inſtances the expanſive power is *naturally* of force ſufficient to produce and maintain

tain fluidity; it may, however, in moſt inſtances, be made to effect this *artificially*. A certain degree of expanſive power exiſts in all bodies; and this has been called the ſpecific heat of the body.

The cooling of a body ſeems to conſiſt in a diminution of the expanſive action on it's ſurface, by an oppoſite power or modification of the fluid on the outſide: when this is very ſtrong, it is ſuppoſed to expel a portion of fire from the body.

When the expanſive action of fire within any ſubſtance becomes greater than is conſiſtent with it's cohefion, it is diſſipated or reſolved into vapour. This, however, may be done in ſuch manner, that the fire may act on the internal parts of the ſeparated body, without ſpending any of it's force upon the parts of external ſubſtances. Hence vapour continues to exiſt in a temperature much below that in which it was originally produced. When this latent fire is transferred to external bodies, the vapour ceaſes to be vapour, or is condenſed; and in ſome caſes returns to it's original ſtate, in others it is productive of light and vehement heat.

A CONCISE VIEW OF DR. CRAWFORD'S THEORY OF ANIMAL HEAT.

For a full view of this admirable theory, I muſt refer you to his work; it is a work that deſerves your ſerious attention, not only from the importance of the ſubject, and the ingenuity and beauty of the theory it propoſes, but from the manner in which it is treated. I know of no work in which the rules of Lord Bacon have been more rigorouſly followed. Here you will find principles inveſtigated with judgment; experiments of the moſt delicate nature, made with care, and deſcribed

bed with accuracy; the deductions natural and luminous. This work will always be considered as a valuable acquisition to science and mankind.

Fire is known, according to Dr. Crawford, 1st, By the peculiar sensations which it excites: considered as exciting these sensations, it is called *heat*. 2. It is known by it's effects upon an instrument that has been employed to measure it, called a *thermometer*; and this is termed the *temperature* of fire in bodies. 3. It has been found by experiment, that in bodies of different kinds, the quantity of fire may vary, though the temperature and weights be the same. When fire is considered relatively to the whole quantity of it contained in bodies of different kinds, but which have the same weight and temperature, it may be termed *specific fire*.* If, for example, the temperatures and weights being the same, the whole quantity of fire in water be four times as great as that of antimony, the specific fire of these substances is said to be as four to one.

Heat is measured by the intensity of our sensations; *temperature* by the expansion of the fluid in the thermometer; *specific fire* by the alterations of temperature, which equal quantities of fire produce in bodies that have equal weights.

Thus two bodies are said to have the same heat, when they equally affect the organs of feeling; and a greater or less degree of heat, as they produce a greater or less effect upon those organs.

Bodies are said to have the same temperature, that produce equal expansions in the thermometer; and the same body is said to have a higher or lower temperature, according as a greater or less degree of expansion is indicated by the thermometer.

The vulgar make use of the human body as a standard

* Crawford's Experiments and Observations on Animal Heat.

ſtandard for the meaſure of temperature; but this is by no means ſufficiently accurate for philoſophical perſons, becauſe the ſenſations of no two perſons agree, nor even thoſe of the ſame perſons at different times.

Dr. Crawford has ſhewn, that the ſpecific fire of bodies, which are of the ſame weights and temperature, is greater or leſs in proportion as greater or leſs alterations are produced in their temperatures by equal quantities of fire. Thus it is found, that the ſame quantity of fire, which raiſes a pound of water one degree, will raiſe a pound of mercury 28 degrees; from whence it has been deduced, that the ſpecific fire of water is to that of mercury, as 28 to one.

As equal weights of heterogeneous ſubſtances are found to contain unequal quantities of fire, there muſt be certain eſſential differences in the nature of bodies, whereby ſome can collect and retain a greater quantity of fire than others. Theſe different powers are called the capacities of bodies for containing fire. Thus, if you find by experiment, that a pound of water contains four times as much fire, as a pound of diaphoretic antimony at the ſame temperature, the capacity of water is ſaid to be to that of antimony, as four to one.

The temperature, the capacity for containing fire, and the fire contained, may be diſtinguiſhed from each other in the following manner. When we ſpeak of the capacity, we mean a power inherent in the heated body; by fire, the fluid retained in the body by means of this power; when we ſpeak of temperature, we conſider fire as producing certain effects upon the thermometer.

The capacity for containing fire may continue unchanged, though the quantity of fire be varied. If a pound of ice be ſuppoſed to retain it's ſolid form, the quantity of fire will be altered by every increaſe or diminution of heat; but as long as it's

it's form or ſtate continues the ſame, it's capacity for receiving is not affected by an alteration of temperature.

A body with a ſmaller capacity for containing fire, has it's temperature more augmented by the addition of a given quantity of fire, than that whoſe capacity is greater. Hence the temperature of a body depends partly upon the quantity of fire, and partly upon the nature of the body containing the fire; and conſequently the temperature may be varied, either by a change in the nature of the body itſelf, or by a change in it's quantity of fire.

If the variation in temperature ariſe from the firſt of theſe circumſtances, it follows, that in the ſame body the temperature may vary, though the fire continues the ſame.

If, for example, a body of a given weight be ſuppoſed to have a capacity as one, a quantity of fire as ten, and the temperature computed from the point of total privation, as if the capacity be conceived to be doubled, the ſame quantity of fire which before raiſed it to the temperature of ten, will now be ſufficient only to raiſe it to five.

Dr. Crawford lays down the following facts as the principles upon which his very curious experiments are founded; which I relate more willingly to you, as they will confirm the greater part of what we have already ſaid to you on the ſubject, and tend to impreſs it more ſtrongly on your minds.

1. *Fire has a conſtant tendency to diffuſe itſelf over all bodies, till they are brought to the ſame temperature.*

Thus if two bodies are mixed together, or placed contiguous to each other, the fire paſſes from one to the other, till they are of the ſame temperature; and all inanimate bodies, when heated and placed in a cold medium, gradually loſe

loſe heat, till they are brought to the ſtate of the ſurrounding medium.

In other words, bodies in contact, or that communicate with each other, will all acquire, after a certain length of time, the ſame temperature, however different their reſpective original temperatures may have been. Two bodies, which when in contact neither receive nor impart heat, are of the ſame temperature. All bodies, therefore, which by direct or ſucceſſive contact communicate with each other, muſt have the ſame temperature, or the fire will diffuſe itſelf among them, till they have acquired a common temperature.

Conſequently the various claſſes of bodies throughout nature, if they were not acted upon by external cauſes, would at length acquire a common temperature, and the fire would be quieſcent; as the waters of the ocean, if not prevented by winds, and by the action of the ſun and moon, would come to an equilibrium, and would remain in a ſtate of reſt. But cauſes continually occur in nature, to diſturb the ballance of heat, as well as that of the waters of the ocean, whoſe waters are kept in a conſtant fluctuation.

2. *Fire is contained in all bodies in conſiderable quantities, when at the common temperature of the atmoſphere.*

We are told by Dr. Pallas, that in the deſerts of Siberia, during a very intenſe froſt, the mercury was found congealed in the thermometers expoſed to the atmoſphere, and a quantity of that fluid in an open bowl placed in a ſimilar ſituation, at the ſame time, became ſolid. Now it has been proved by experiments made at Hudſon's-Bay, that the freezing point of mercury is very nearly 40 degrees below the zero of Fahrenheit's ſcale: to this degree the atmoſphere in Siberia muſt have been cooled. From a paper read at the Royal Society, we learn

learn that in the winter, 1785, a ſpirit of wine thermometer fell to 42 below 0 in the open air at Hudſon's-Bay; and from the ſame communication we find, that by a mixture of ſnow and vitriolic acid, the heat was ſo much diminiſhed, that the ſpirit of wine thermometer ſunk to 80 below 0, that is, 112 degrees below the freezing point of water. It is therefore plain, that there is a conſiderable quantity of fire acting in all bodies, when at the common temperature.

3. *If the parts of the ſame homogeneous ſubſtance have a common temperature, the quantity of fire will be proportional to the bulk or quantity of matter.*

That is, a pound of gold contains an equal quantity of fire, with another pound of gold at the ſame temperature, and a pound of water an equal quantity with another pound of water; and the quantity of fire in two pounds of water is double that which is contained in one pound, when at the ſame temperature.

4. *The dilatations and contractions of the fluid in the mercurial thermometer, are nearly proportional to the quantities of fire which are communicated to the ſame homogeneous bodies, or ſeparated from them, as long as they remain in the ſame ſtate.*

Thus the quantity of fire required to raiſe a body, four degrees in temperature, by the mercurial thermometer, is nearly double what is required to raiſe it two degrees, and four to raiſe it one degree, and ſo on in proportion.

The capacities of bodies for containing fire are nearly permanent, as long as they retain the ſame form.

The capacity of a body for fire is ſaid to be permanent, when the ſame quantity of fire which raiſes it to one or two degrees, as meaſured by an equi-differential thermometer at a given temperature, will raiſe it an equal number of degrees at

all other temperatures. On the contrary, the capacity is ſaid to be increaſed or diminiſhed by an alteration of temperature, when, in conſequence of ſuch an alteration, a greater or leſs quantity of fire muſt be applied to produce an equal effect upon the thermometer.

We have already ſhewn you, that the mercurial thermometer is nearly an accurate meaſure of heat, and that when equal portions of warm and cold water are mixed together at different temperatures, the mercurial thermometer indicates very nearly an arithmetical mean; and conſequently that the capacity of water is permanent in all the intermediate temperatures between the freezing and boiling points. For if, when the heat augmented, the capacity of water was increaſed, an equi-differential thermometer would point to more; and if diminiſhed, leſs than the arithmetical mean.

If two equal and ſimilar bodies that differ in temperature, be brought together, they will by communication acquire a common temperature, and their quantities of fire will by that means be rendered equal: that is, the hotter of the two bodies will have communicated half it's exceſs to the colder; therefore the quantity of fire in one of theſe two equal bodies, will be an arithmetical mean between the two quantities originally poſſeſſed by each of them; in other words, it's temperature will exceed the colder exactly as much as it falls ſhort of the hotter body.

If the two bodies had been unequal, they would alſo acquire a common temperature by communication, but the exceſs of fire would not have been equally divided between them. For the quantity of heat in ſuch bodies is in proportion to their quantities of matter; and the exceſs of heat in the hotter body, is divided between them in proportion to their weights.

From

From hence it is concluded, that the quantity of fire required to be added to or taken from bodies of the ſame kind, to produce equal changes of temperature, will be in proportion to their quantity of matter.

5. *Unequal quantities of fire are required to produce equal alterations of temperature, in equal weights of heterogeneous bodies.*

Thus, if the temperature of a pound of mercury be raiſed one degree, and that of a pound of water one degree, it will be found, that unequal quantities of fire have been communicated to the mercury and to the water.

If a pint of mercury at 100, be mixed with an equal bulk of water at 50, the change produced in the mercury will be to that produced in the water as 3 to 2. From whence it is inferred, that the fire in a pint of mercury, is to that in a pint of water as 2 to 3; or that the ſpecific fire in theſe bodies is reciprocally proportional to the changes of heat produced in them, when they are mixed together at different temperatures.

To illuſtrate this further, let four pounds of diaphoretic antimony at 20 be mixed with one pound of ice at 32, the temperature of the mixture will be nearly 26. The ice will be cooled 6 degrees, and the antimony heated 6 degrees. Reverſe the experiment, and the effect will be the ſame. Take 6 degrees of heat from four pounds of antimony, and add it to a pound of ice, the latter will be heated 6 degrees. The ſame quantity of fire, which raiſes a pound of ice 6 degrees, will raiſe four pounds of antimony 6 degrees.

If this experiment be made at different temperatures, you will have the ſame reſult: now as the power (capacity) by which bodies retain and receive fire, remains the ſame while they retain the ſame form, not being altered by a change of tem-

perature; it follows, that the ſame quantity of fire which raiſes ice 200, or any given number of degrees, would raiſe the antimony an equal number of degrees. 1 lb. of ice, therefore, and 4lb. of antimony when at the ſame temperature, contain equal quantities of fire. But four pounds of antimony contain four times as much fire as one pound: therefore the quantity of fire in a pound of ice is to that in a pound of antimony as four to one.

That you may underſtand this ſubject better, I ſhall now ſtate it more accurately in Dr. Crawford's words. Dr. Black perceived, that by mixing together bodies at different temperatures, an eſtimate might be formed of their comparative quantities of heat, or of their capacities for containing that element.

Thus when a hot and cold body are mixed together, if their capacities for heat be *equal*, the diminution in the temperature of the former, and the increaſe in that of the latter, will be half the difference of the ſeparate heats; or the thermometer immerſed in the mixture, will point to an arithmetical mean. But if their capacities for heat be *unequal*, the common temperature of the mixture will not be the arithmetical mean; it will be nearer to the original heat of the body, which has the greater capacity, than to that of the other. If, for example, a pound of mercury at 79 be mixed with a pound of water at 50, the temperature of the mixture will be 51; or the mercury will be cooled 28 degrees, and the water will be heated only one degree. Hence Dr. Black inferred, that water has a much greater capacity for heat than mercury.

Having thus diſcovered a meaſure for determining the comparative quantities of heat in bodies, it was found by a ſeries of trials which were inſtituted by Dr. Black and Dr. Irvine upon metallic and ſaline bodies, that the element of fire is

diſtributed

diſtributed in various proportions throughout thoſe ſubſtances, or in other words, that in equal weights they contain unequal quantities of elementary fire. 2. It likewiſe appeared, that when bodies undergo a change of form, their capacities for containing heat or elementary fire, are, for the moſt part, ſuddenly increaſed or diminiſhed. When their capacities are diminiſhed, they part with a portion of their elementary fire; and when their capacities are again increaſed, they re-abſorb an equal portion of fire from the ſurrounding bodies. Dr. Black has ſhewn in particular, that when ſolid bodies, by expoſure to heat, are changed into liquids or into vapour, they abſorb a quantity of elementary fire, which is neceſſary to their exiſtence in the liquid or vaporific form; and that on the contrary, when vapours are condenſed, or non-elaſtic fluids are congealed, they part with the heat which they had before abſorbed.

In reflecting on theſe facts, *Dr. Crawford* thought it probable that by meaſuring the comparative quantities of fire in the ſolid and fluid parts of animals, as well as in alimentary ſubſtances, he might be enabled to trace the ſource of animal heat.

The reſult of his inquiry led not only to the cauſe of this phenomenon, but likewiſe to that of the heat produced by the inflammation of combuſtible bodies.

The evidence upon which his doctrine reſpecting the cauſe of animal heat and combuſtion depends, is compriſed in the following propoſitions.

1. The quantity of heat contained in pure air is diminiſhed by the change which it undergoes in the lungs of animals; and the quantity of heat in any kind of air that is fit for reſpiration, is nearly proportioned to it's power in ſupporting animal life.

2dly,

2dly, The blood which paſſes from the lungs to the heart by the pulmonary vein, contains more abſolute heat (fire) than that which paſſes from the heart to the lungs by the pulmonary artery.

3dly, The comparative quantities of heat in bodies, ſuppoſed to contain phlogiſton, are increaſed by the changes which they undergo in the proceſſes of calcination and combuſtion.

4thly, When an animal is placed in a warm medium, the colour of the venous blood approaches nearer to that of the arterial, than when it is placed in a cold medium; the quantity of reſpireable air which it phlogiſticates, in a given time, in the former inſtance, is leſs than that which it phlogiſticates during an equal ſpace of time in the latter; and the quantity of heat produced when a given portion of pure air is altered by the reſpiration of an animal, is nearly equal to that which is produced when the ſame quantity of air is altered by the burning of wax or charcoal.

Having eſtabliſhed the truth of theſe propoſitions by direct experiments, Dr. Crawford deduces from them the following explanation of the cauſe of animal heat and combuſtion.

The purer part of the atmoſpherical air received into the lungs of animals in reſpiration, is converted by it's union with the inflammable principle of the blood into fixed air, and aqueous vapour. It appears by experiment, that the quantity of elementary fire contained in pure air, is to that contained in fixed air, and aqueous vapour, nearly as three to one.

Hence it follows, that in the proceſs of reſpiration, the pure air muſt neceſſarily give off a conſiderable proportion of it's elementary fire. It moreover appears from the ſecond propoſition, that the blood in it's paſſage through the lungs, has the quantity of it's elementary fire increaſed; and conſequently

ſequently in the proceſs of reſpiration, a portion of that element muſt be abſorbed by the blood. The truth of this inference is farther confirmed by the reſults of the experiments which were adduced in proof of the third and fourth propoſitions.

For from the third propoſition it appears, that when bodies are united with the inflammable principle, they part with a portion of their elementary fire, and that when this principle is again diſengaged, they re-abſorb an equal portion of fire from the ſurrounding bodies. It moreover appears from the experiments of Dr. Prieſtley, that in the proceſs of reſpiration the inflammable principle is ſeparated from the blood, and combined with the air. Hence it follows, that the quantity of elementary fire in the former muſt be increaſed, and that in the latter diminiſhed. This concluſion is ſtill further corroborated by the fourth propoſition; whence it appears, that the *quantity* of the inflammable principle diſcharged, and of elementary fire abſorbed, in the proceſs of reſpiration, is greater or leſs, in proportion as the animal is expoſed to a colder or to a warmer medium. The explanation of the cauſe of combuſtion is as follows.

It appears, by experiment, that the purer part of atmoſpherical air contains much elementary fire; that when it is converted into fixed air and aqueous vapour, the greater part of this fire is detached; and that the capacities of bodies for containing heat are increaſed by the changes which they undergo in the proceſs of combuſtion.

Hence it is inferred, that the heat which is produced by combuſtion, is derived from the air, and not from the inflammable body; for inflammable bodies contain little elementary fire. Atmoſpherical air, on the contrary, abounds with this principle. In the proceſs of inflammation, the

pure air is, for the moſt part, converted into fixed air and aqueous vapour, and at the ſame time gives off a great proportion of it's fire, which, when extricated, ſuddenly burſts forth into flame, and produces an intenſe degree of ſenſible heat. It is inferred, on the contrary, that no part of the heat can be derived from the combuſtible body; for the combuſtible body, during the inflammation, undergoes a change ſimilar to that which is produced in the blood by the proceſs of reſpiration, in conſequence of which it's capacity for containing heat is increaſed; it therefore will not give off any part of it's heat; but like the blood, in it's paſſage through the lungs, it will abſorb heat. Hence Dr. Crawford concludes, that the ſenſible heat, which is excited in combuſtion, depends upon the ſeparation of fire from the purer part of the atmoſpherical air. If the quantity of air, which is changed by the proceſs of combuſtion in a given time, be very great, the change is attended with much light, with a vivid flame, and with intenſe heat; but if the alteration in the air be ſlow and gradual, the heat paſſes off imperceptibly to the ſurrounding bodies.

It is hardly neceſſary to obſerve to you, that Dr. Crawford's ingenious theory differs, in ſome reſpects, from what has been already laid down in theſe Lectures; it remains for you to decide which is moſt conformable to natural appearances. In this deciſion you will be aſſiſted by the facts and conſiderations that will be introduced in ſome of the ſubſequent Lectures. I ſhall therefore conclude this with a few general obſervations on the doctrine of capacities for fire.

No proper eſtimate can be made of the quantities of heat bodies are capable of giving and receiving, unleſs fire never acted in any other way than by affecting or dilating the volume.

This,

This, however, is not the caſe; for fire appears to reſiſt other actions of bodies beſides that of gravitation. Unleſs therefore it be ſuppoſed, that in the various compoſitions, which take place even in the moſt homogeneous ſubſtances, the different kinds of matter are equally proportioned and diſpoſed, no rule can be properly formed with regard to the quantity of heat, which bodies of different ſubſtances ſhould give or receive, when the equilibrium of heat among them and ſurrounding bodies is changed.

But further, the weight of bodies is not the part which ſhould be conſidered in the theory of capacities; it is their volume, or the ſpace they occupy, which ſhould be chiefly attended to; for a *vacuum*, which has no weight, contains fire. Nor are the different degrees of tendency among the particles of the ſubſtances to be noticed in this theory; for in a vacuum there is no ſenſible ſubſtance to reſiſt the dilatation of fire, yet it is as much compreſſed, or ſhews the ſame degree of expanſibility as in other ſubſtances of the ſame temperature. From hence it is highly probable, that the phenomena of capacities are occaſioned by the expanſive faculty of fire; for no one can doubt, that at the ſame temperature, and with the ſame volume, but what there is leſs in a vacuum than in other bodies.

Although the Torricellian vacuum, when well made, ſeems deprived of every ſenſible ſubſtance, a thermometer included in this place would conform itſelf to the exterior temperature, as if it were in the air, in water, or any other ſubſtance. If then it's expanſive faculty does not augment in this ſpace, where it is the only known ſubſtance, it ought to be in greater quantities there than in any other equal ſpace occupied partly by the particles of another ſubſtance. But it is probable, of

equal

equal ſpaces, it is that which contains the leaſt fire: if any one doubts this conjecture, let him try it by experiment, according to the preſent theory of capacities; but firſt let us inquire of him what *weight* he would aſſign to the *vacuum?* *

The capacity of bodies, with reſpect to heat, ſuppoſes two things, 1. That there is a quantity of *diffuſible fire* to be communicated among bodies: and 2dly, that there is an equilibrium ſtate of heat to be formed among them, by each giving or receiving it's proper quantity. This transferable ſubſtance may be termed *diffuſible fire*, to diſtinguiſh it from the *conſtitutional fire* of bodies, which is not immediately diffuſible.

In the conſtitutional fire of bodies, two ſpecies may be diſtinguiſhed, according as the bodies are ſolid (concreted) or fluid. But every natural body muſt have a certain degree of conſtitutional fire, without which the diſtenſion of the body would be extinguiſhed by the condenſing powers. Thus then is the *conſtitutional fire of volume*, or power of diſtenſion, neceſſarily oppoſed to a certain quantity of gravitating or condenſing power.

Volume, in natural bodies, is an eſſential quality, and fire acting as heat in volume, is an eſſential principle. There is therefore in bodies a conſtitutional degree of heat which cannot be ſeparated; and it is only the ſuperfluous heat, which may be diffuſed among bodies, according to their capacities for receiving it.

But as volume in bodies is a changeable quality, there may be a certain quantity of fire, which in one degree of diſtenſion may be conſidered as conſtitutional for that particular volume, which in another degree, or in a different volume, might become ſuperfluous and diffuſible.

Bodies

* De Luc's Letters in the Journal de Phyſique.

Bodies are found to be compoſed of two different kinds of matter, and to ſubſiſt in three diſtinct ſtates or modifications of their compound ſubſtance; which three ſtates are commutable, according to the changed proportions and circumſtances of the matter or conſtituent principle. Hardneſs may be conſidered as the firſt of thoſe ſtates, in which the power of concretion, as well as gravitation, is found to prevail. Secondly, there is ſoftneſs or fluidity, in which nothing but the power of gravitation is perceived, and when the power of concretion is ballanced by a certain quantity of fire, diſtinguiſhed by the name of latent fire. And thirdly, we find the ſtate of fluid elaſticity, where not only the power of concretion is ballanced by a certain quantity of fire, but alſo the power of gravitation, which ſhould tend continually to diminiſh the volume of the body, is oppoſed by another quantity of fire, imparting elaſticity and expanſion to the ſubſtance of this body.

The diffuſion of fire is an action and effect of this matter, diſtinctly different from thoſe which are produced by oppoſing the gravitation and concretion of matter in a body.

The diffuſion of fire is a peculiar action thereof, and which, like every other event, takes place only when the proper conditions for this action ſhall arrive; it is therefore by knowing thoſe conditions that this operation in bodies is to be underſtood, as it is by the changed volume, and different ſtates of bodies with reſpect to hardneſs and fluidity, as alſo by our ſenſations, that this diffuſion of fire, from one body to another, may be concluded as having taken place.

To purſue this element in it's various modifications, you muſt diſcriminate the action of fire, when it oppoſes and ballances the action of gravitation and of hardneſs, from that operation of tranſition,

transition, by which it is translated from one body to another, or by which without changing the body it leaves the opposition and ballance of one power in order to resist another. This elective action of fire necessarily requires conditions, without which matter never acts. But such is our imperfect knowledge of the constitution of material things, that we cannot attempt to give a detail of the conditions by which the action of transition in fire may be influenced or affected.

Though we cannot perceive the condition of these actions, yet enough has been investigated to discover *wisdom* in the laws of actions, by which those conditions are conceived to be rendered subservient to certain ends. The manifold operations necessary to produce hardness, softness, fluidity, &c. in all their various degrees, are conducted amidst powers indefinitely multiplied, combined, and opposed; yet there does not appear the least confusion or disorder in the effect.

I have now finished the Lectures on fire, in which I have given you a general account of it's agency and operation. You have seen it produce the most wonderful changes in bodies: these and various of it's effects are well known, while it's own nature still remains amongst the most inscrutable mysteries. It manifests itself in a variety of forms, a diversity and apparent contrariety of effects; it dwells in the most compacted ice, and is quiescent in the dark flint, yet diffuses a world of light through the planetary system. It's operations are reducible to no standard; for it acts according to the kingdom in which it moves, and the subject it possesses; in heaven it is a celestial fire, and the principle of a joyous life; in hell it is a hellish fire, and a source of torment; in this mixt world of good and evil, it assumes more forms than

Proteus.

Proteus. It flashes in lightning, and faintly illumines the glow-worm's feeble lamp; it warms us by the consumption of our fuel; it destroys and preserves life, and is the root of all vitality, from the highest archangel to the least minim in nature. Without it there would be neither vegetation, nor animality, nor appetite, nor conjunction, nor fecundity, nor growth. In a word, it may be considered in it's ministry, under the *Omnipotent Artificer*, as the soul of the world, and the life of creation.

The rays of the sun, or the heat of an artificial fire, which is equivalent, are so absolutely necessary to the growth of herbs, that in their season for taking in the sap, in their stature, and in their qualities they are wholly influenced by the solar rays. The plants which are lowest in stature appear first early in the spring; these are succeeded by others of a larger size, till at last the under shrubs and trees put forth in their order; when the sun is at it's greatest exaltation in summer, the whole vegetable creation is in it's greatest glory and beauty. As the sun declines, this vegetative motion languishes; and the order they observed in putting forth their leaves, flowers, and fruits, is now inverted in their decay; the tallest trees are generally the first that drop their leaves, and the lower follow at a proper distance, till by degrees the smallest shrubs, except ever-greens, are all stript of their covering, and so continue till the sun, at his return, puts new life and moisture into their veins. It is to the powerful agency of fire you must recur to account for the alterations of which the bodies of vegetables and animals are susceptible. The motion of the sap, the mild fermentation which ripens fruit, the composition of animal fluids, their decomposition, successive changes and putrifraction,

tion, in these and infinitely other phenomena, fire is the governing principle.

Air, *light*, and *fire*, are the instruments, which God has manifestly ordained as secondary and subservient to his own power in the œconomy of the material world; and they are so universally extended and incorporated with other things, as to be serviceable in the motion of all it's particular parts. One or the other of these is present to all those effects which have fallen under the observation of philosophers. This conclusion may indeed be deduced from premises plain and obvious, without the assistance of philosophy or the mathematics. For what learning is necessary to discover that *light* gives sight to the eyes? that *air* is the breath of life? and that without *fire*, applied to it's proper degree, the blood is congealed and the limbs are inflexible? All this is evident to the most undisciplined apprehension: for a man is no sooner born into the world, than he makes most of the experiments necessary for obtaining this knowledge; and he may challenge the most subtle philosopher, to name the substance or fluid that can supply the place of either of them.

Before I quit this subject, it will not be unentertaining to take a short view of some parts of mythological learning. "When the world," says the learned author of the Trinitarian Analogy, "by following it's own wisdom, departed from the true God, they left the substance, and kept the shadow; they worshipped the creature instead of the Creator: but still they were right thus far, in that they retained as the objects those very elements of the natural creation, which had been appropriated to give them ideas of the Creator. In this capacity as substitutes, they were the *truth of God*; but when deified in themselves, and taken as principals, they were *changed into a lie*.

"Fire,

"Fire, light, and air, the ſcriptural emblems, were univerſally adored throughout the heathen world. Moloch in Syria, Apis in Egypt, Vulcan in Greece and Italy, were names given to the element of *fire*. Light was worſhipped under the names of Apollo, Mithras, &c.* No Latin ſcholar need be told that Jupiter was the air; the poets, even uſing the proper name of Jupiter, as an appellative term to ſignify the air; and all the epithets given to him are applicable to the ſame element."

This I ſhall further develope in the hiſtory of *Vulcan*, who in the general ſenſe ſeems to be the univerſal fire diffuſed through *the vaſt maſs* of inert matter, which in a prior form was thought to be water. The moſt ancient philoſophers of Egypt and Greece agreed in conſidering water as the matter, the hyle, or mother of all things; and fire the father of it's life and animation.†

Fire, the moſt active, univerſal, and prolific agent, cannot operate upon itſelf; it requires a wife, a female, a lower matter whereby to manifeſt it's aſtoniſhing and various effects; and when matter or *Venus* is united thereto, fire, which ſeems one ſimple and uncompounded eſſence, puts on ten thouſand beautiful forms, colours, and motions, through every department of nature; from minerals, by a gradual aſcent, to vegetables, to animals, to man.

When the ſpark or atom of fire lies hid in primary

* Bacchus, or wine, is the ſolar fire in the juice of the grape, ſo tinctured with it's genial beams, as to be capable, when drank with temperance and moderation, to exhilarate the body, mind, and imagination.

† See R. Clarke's Series of Letters, Vol. 1.
Jones's Phyſiological Diſquiſitions.
——— Letters from a Tutor to his Pupil.
Harris's Hermes.
Maurice's Hiſtory of Hindoſtan.

primary matter, it is dark, deformed, and no ways promiſing ſuch a fair contexture and life as it will be clothed with when it has built it's houſe or body, in which it ſeems dormant awhile. In this ſenſe it was Vulcan *deformis*.

But fire united with matter, Vulcan to Venus, or matter yielding to the ſignatures impreſſed by this univerſal agent, is the father of the wonderful variety as well as uniformity ſo conſpicuous in the great theatre of the viſible world. Being dark and inviſible in it's internal operation, when bedded in the ſeed and center of all things; Vulcan, in reference to this ſtate, may be well called black and ugly. Conſider any ſeed, ſee how it putrifies, grows black and fœtid, before it riſes into a new life of vegetation and animation; and who would think that this deformed proceſs in nature, the handmaid of Providence, ſhould lead to the evolutions of ſuch variegated beauties and powers as nature aſſumes, in the diverſity of corporeal forms, in every ſcale of being animate and inanimate, ſenſitive and rational?

Vulcan repreſenting the principle of fire in nature, was conſidered as married to Venus, who ſprung from the ſea or watery element; thus is this wife the apparent mother of grace, beauty, colour, figure, and motion; for with the ancients matter in every living form began from water, and having paſſed through various changes effected by fire, manifeſts that inexpreſſible variety diſplayed through all the creation. Hence Venus, or water, riſing up into the forms of trees, flowers, and vegetables, into birds of variegated plumage, into animals of different kinds of cloathing, and laſtly and moſt perfectly in man the microcoſm, was called the mother of the graces, moſt beautiful and naked, becauſe nature in all it's profuſion of forms and colours, is moſt amiable in her own ſimplicity.

Vulcan

Vulcan was *tardipes*, or ſlow-footed, becauſe in the theatre of nature his ſteps are ſcarce perceptible, and his progreſs ſo ſlow and gradual, as not to be ſeen but at diſtant intervals. From this ſmall ſpecimen, which I muſt leave you to purſue further for your own profit and entertainment, you will be led to ſee, that there is a ſtriking alliance between the theology of ſcripture, the conſtitution of nature, and the mythological myſteries of heatheniſm. I ſhall only obſerve further, that ſcripture ſeldom, if ever, reproaches the nations for deifying men, but for worſhipping the ſun, moon, planets, earth, air, and water, under fanciful images of their own invention, after the forms of men, beaſts, planets, &c.

2dly, That all diſtinguiſhed names are formed from alluſions to fire and light, and that language diveſted of metaphorical and topical expreſſions deduced from this ſource would loſe all it's ſpirit and energy.

The Rev. Mr. Jones has ſhewn, that the account of the generation of the world, and it's preſent œconomy, is revealed in ſcripture, not with the deſign of ſending us to ſchool to learn philoſophy as a ſcience, but with a view to the intereſts of religion, and therefore ſo far only as religion is concerned; and that nature is referred to in the Bible for three great ends: 1ſt, To guard men from error. 2dly, To open their underſtanding by explaining ſpiritual truth from natural imagery. 3dly, To inſpire them with ſentiments of devotion. The whole is ſo performed as to guard the Hebrews from the dangerous and profane doctrine of the gentiles, who like modern philoſophers conſpired univerſally to deify nature, and confound the Creator with his works; and to give to the world itſelf that adoration which is only due to it's maker.

The ſcripture therefore ſets forth the power of

of the true God, the maker of heaven and earth, and deſcribes the natural dominion of the elements as dependent on the power of the Creator: that the ſun, the moon, and the hoſt of heaven, obſerve the law they received from him in the beginning of the world, of which ſubordination and dependance the heathens had loſt the knowledge, through the affectation of philoſophical wiſdom, till at length nature itſelf took the place of the Creator; the ſubſtance of the elements was confounded with the ſubſtance of the Deity; the ſubtle matter of fire was held to be the ſoul of the world; the powers of heaven and earth became ſo many diſtinct divinities; and the hiſtory of their operations was converted into a religious myſtery, ſuch as you every where find in the occult doctrine of the Pagan mythology.*

The ſource of the hieroglyphical language of the ancients can only be traced with certainty from the ſcriptures. It is dependent on an important truth, that the viſible world is repreſentative of the inviſible; that the properties, forms, and motions of the one, were copies, images, and ſhadows of the attributes, qualities, and laws of the other. The knowledge therefore of philoſophy, when in it's proper place, enlarges the underſtanding, by giving it a proſpect of both worlds, of one from the other, of the inviſible from the viſible. The powers of nature are ſymbolical of the powers of the Deity, and are applied in that capacity in numerous paſſages of ſcripture.

* Jones's Phyſiological Diſquiſitions, introduction, p. xv.

OF THE

NATURE AND PROPERTIES OF

ELASTIC FLUIDS.

LECTURE X.

EVERY thing around us, all that is within us, as it were with one voice ſpeak the language of the apoſtle, and aſſert that GOD IS LOVE. Examine the material ſyſtem extending throughout heaven and earth, and it preſents you with a variegated ſcene rich in uſe and beauty; for far and wide as is the vaſt range of exiſtence, ſo far is the divine benevolence extended. You will find the meaneſt and minuteſt objects not without their uſe and importance, the moſt diſtaſteful not without their ſweetneſs, the moſt jarring and diſcordant not without their order and harmony; the moſt dark and ſhaded, the moſt crooked and deformed, giving luſtre to others, and recommending the ſhapely and the beautiful.

The learning and philoſophy of ages have been employed in exploring the works of the *Creator*; which the more they are examined, conſpire ſtill the more to manifeſt his wiſdom and goodneſs: evident proofs of this you will find in the preſent Lecture. The uſes and ends, the objects and organs in the natural and moral world, both the littleneſs and greatneſs of the phenomena, give the cleareſt, the ſtrongeſt, and moſt ſtriking proofs of a beneficent Creator. The univerſe, ſeen by a

devout eye, appears as an immenſe ſphere depending by a chain of gold from the throne of God, inſcribed on every ſide with divine characters, moving in divine order and harmony, and reſplendent with divine light and beauty.

But though the *kingdom of God* is in ſome ſort expreſſive of the nature and character of it's *Author* and *King*; yet the diſplays thereof are partial and confined, ſuited to the capacities of it's ſeveral ſubjects, but opening and enlarging in proportion to the improvements they make in every preſent diſpenſation. Though the kingdom of God is like his attributes, ever full and perfect; yet with reſpect to us, it muſt ever be partial and progreſſive, adapted to the ſtate of our natural and moral capacities: it is perfect in every ſpring and wheel as in the whole machine, in the origin as in the progreſs and conſummation. Divine philoſophy, like an optical cylinder, ſets all objects right, ranges them in their due places, and raiſes what appears to the naked eye a confuſed heap of lines, colours, and figures, into regular forms, members, and bodies.

Every individual being, or production in nature, even the minuteſt, when enlarged to the human ſight by a microſcope, is a *ſpectacle of beauty*. As much, even of the external world, of *ſky*, *ocean*, and *earth*, as the human eye is able to take in at one view from the ſummit of a high hill, in a fertile country near the ſea, in a ſun-ſhiny day, or in a ſtar-light night, affords the moſt ſublime and magnificent ſcene of *corporeal beauty* conceivable by man. Now all this beauty, beauty reſulting from the *orderly diſpoſition* of various *parts*, and the *harmonious compoſition* of them together in one *whole*, is open to the view of all men. Theſe and other beauties every where ſurrounding us, are as eaſily perceived by the unlettered peaſant, as the beſt informed philoſopher.

But

But besides what is thus daily obvious to an ordinary beholder's eye, the deep-searching *fossilogist*, the far-travelling *botanist*, the curious *florist*, and the inquisitive *zoologist*, are in every age going on to discover *new* objects of *beauty*, in those parts of nature which most engage their attention and admiration. The laborious *astronomer* is employed in discovering more and more regularity, harmony, and connection in the motion of the celestial bodies, and consequently more and more of *order* and *beauty* in the great mundane system. The experimental *chemist*, and the ingenious *physiologist* are *gradually* unfolding the hidden *measures* and *proportions* used in mixing the elementary and minute parts of nature, in compounding these mixtures, and in decompounding her composite parts, that they may thus discover, how out of *invisible* materials, bodies are framed *visible* to the eye of outward sense. In a word, every advancement made in *physical knowledge* is a new discovery of some *beauty* unseen before; and of such discoveries, I presume, there never can be an end, and that man can never attain to a complete knowledge of the beauties manifested in nature.

Wide as the extent of the universe is the wisdom of it's workmanship, not bounded and narrow like the humbler works of *art*: these are all of origin no higher than *human*. We can readily trace them to their utmost limit, and with accuracy discern both their beginning and their end. But where is the microscope that can shew us from what point wisdom begins in nature?* Where the telescope that can descry to what infinitude it extends? The more diligent our search, the more accurate our scrutiny, the more we are convinced that our labours can never finish, and that subjects inexhaustible remain behind still unexplored.

Enough, however, of this knowledge is, and

 perhaps

* Harris's Hermes.

perhaps in all ages hath been amongst men to authorize the following conclusion, that outward nature throughout the universe is full of beauty; and from this conclusion another will rationally follow, regarding the relation between *effect* and *cause*, that the *fountain* of all this beauty, is beauty *original*, beauty *itself*, beauty *universal*, the final and formal cause of all that *good* which is enjoyed by beings who are capable of any enjoyment, and of all that *beauty* which is enjoyed by such as have a sense of beauty. *Supreme Spirit!* thine is the divine charm by which mountain and valley, forest and ocean, wondrous animal, and a whole creation, in beauty and proportion arise to being. Let but a few attractions cease, in whose bonds you grasp them, and the magic universe is at an end; it is without form and void, and the very ruins thereof are not to be found.

As you proceed in these studies, you will find philosophers drawing from scientific sources ample stores of useful inventions, and extending their speculations to practical purposes and objects of great utility; and you will be led to think with *Lord Bacon*, that when men have, by proper induction, attained a knowledge of the intimate qualities and laws of things, they may in the end command nature, and perform works as much greater than we suppose practical by the powers of natural magic, as the real actions of a Cæsar surpass the fictitious ones of the hero of a romance.*

Since philosophy has soared into the regions of invisible aerial substances, has explored their nature, and investigated their constituent principles, many hidden veins of science have been opened, much wealth has been acquired, and fair hopes of reward present themselves to future labourers,

* Sir John Pringle's Discourses.

bourers. You will here ſee how art can, from mere chalk, unfetter a copious elaſtic fluid, the poiſon of man, or his medicine, according to the mode of application; which, though *inviſible*, yet diſſolves earth and metals, and imparts ſpirit and virtue to the moſt valuable mineral waters. You will here learn more of that vital air, of which we have already diſcourſed ſo much. You have already ſeen how neceſſary it is to combuſtion; you will now ſee how neceſſary it is to animal life, and be made acquainted with the reſources of nature, for purifying our atmoſphere, which is infected from various cauſes; and learn how it is repleniſhed with this ſalutary and vivifying fluid. The ſubject of the preſent Lecture is indeed intimately combined with the preceding. All aerial fluids owe their elaſtic property, and aeriform ſtate, to fire; ſo that you are here only entering into another province of the empire of this element.

Van Helmont was acquainted with the inflammable qualities of ſome vapours, and knew that others extinguiſhed flame, and ſuffocated animals, but had no idea that thoſe ſubſtances were capable of being ſeparately exhibited in the form of a permanently elaſtic vapour not condenſible by cold.

Mr. Boyle, obſerving how much air was concerned in moſt of the phenomena of nature, and how neceſſary it was to the exiſtence of animals, became ſolicitous to know whether a fluid of ſo great importance was not producible by art; alſo believing, that ſuch air might be made ſerviceable to the art of diving, and in *ſubmarine* navigation.* With theſe views, that admirable naturaliſt ſet about making ſome new experiments; and from a variety of bodies, by different proceſſes, obtained a

 pneumatical

* An attempt of Cornelius Drebell to make a veſſel to row under water with men in it.

pneumatical fluid,* anſwering his, then, only criterion of air, in being of a durably elaſtic nature. He ſoon diſcovered that theſe new productions were very different from common air, as they preſently extinguiſhed flame, and ſuffocated thoſe animals that attempted to breathe in them.

Theſe experiments were afterwards reſumed by the Rev. Dr. Hales, a man worthy of our beſt eſteem, for his amiable as well as philoſophic qualities. He confirmed and extended the diſcoveries of Mr. Boyle, ſhewing not only that air entered into the compoſition of moſt bodies, but aſcertained alſo the proportion it bore to the reſt of the compound. Dr. Hales examined likewiſe the mineral waters, and found them abound with air; to that circumſtance he aſcribed their ſpirit and briſkneſs, but he did not apprehend that the air he produced was not common air, and of the ſame kind with that Mr. Boyle had extracted from fermenting and effervеſcing liquors. It muſt be owned, it was hard to conceive how theſe ſprings ſhould owe their prime virtues to what in another manner of application is ſo deſtructive of vitality. His experiments are ſo numerous and ſo various, that they are partly eſteemed the ſolid foundation of all our knowledge of the ſubject.

Dr. Browning ſeems to have been the firſt perſon who began clearly to unfold this myſtery, and ſhew that the waters of Pyrmont, Spa, &c. owed their pungency, and that volatile principle on which their virtues chiefly depend, to *an elaſtic aerial fluid.*

The greateſt improvement in this part of pneumatics, ſeems to have originated with Dr. Black, profeſſor of chemiſtry in Edinburgh, and Mr.

* From ripe fruit, fermenting and effervеſcing liquors, and from the putrifaction of animal and vegetable ſubſtances.

Mr. Cavendiſh, F. R. S. The influence of Dr. Black's diſcoveries has been very extenſive, for from his ſchool they were diſſeminated throughout Europe, by men zealous of promoting the principles of their great maſter. Dr. Black firſt ſhewed the cauſe of the cauſticity of alkalies and quick lime, the effect of adding fixed air to theſe bodies, and of depriving them thereof; he ſhewed that it was the preſence of fixed air in theſe ſubſtances that rendered them *mild*; that when deprived of it they are in that ſtate which has been called *cauſtic*, from their corroding and burning animal and vegetable ſubſtances; and by theſe and other diſcoveries, explained in a clear and ſimple manner, many appearances in chemiſtry till then deemed the moſt unaccountable.

Mr. Cavendiſh added to the method of Boyle and Hales for obtaining permanently elaſtic fluids, the mode of transfuſing them from one veſſel to another, and of ſubjecting them to examination. By his ingenious and ſtatical mode of operating, he has given a practicability and accuracy to what is now called the *pneumatic apparatus*, which has ſince been applied with extraordinary ſucceſs, together with many other important diſcoveries. There is no one who has enriched this ſubject more than Dr. Prieſtley, or has analyzed the fugacious element of air with more ſucceſs; very few pages on theſe ſubjects will be found that do not contain ſome diſcovery of his, or ſome improvement on the hints he has ſuggeſted; and ſcience will ever be indebted to him for his valuable diſcovery of pure vital air.

To point out the diſcoveries of *Dr. Prieſtley* in this branch of ſcience, would incroach too much upon our time; his labours far exceed thoſe of his predeceſſors, both in extent and importance. I muſt not, however, forget to mention M. Lavoiſier and Scheele, who for luminous order, accuracy of inveſtigation, and force of mind, are

are unequalled among the promoters of aerial ſcience.

Here another labourer in ſcience preſents himſelf to our view, *Mayow*,* who ſilently, and unperceived in the obſcurity of the laſt century, diſcovered, if not the whole ſum and ſubſtance, yet certainly many of thoſe ſplendid truths which adorn the writings of Prieſtley, Scheele, Lavoiſier, Crawford, and other philoſophers of this day.

"He threw away with ſcorn the vague ideas annexed by the old chemiſts to the terms ſulphur, mercury, &c. He has clearly preſented the notion of phlogiſton, which rendered the name of Stahl ſo celebrated. He perceived the action of vital air in almoſt all the wide extent of it's influence. He was acquainted with the compoſition of the atmoſphere, and contrived to make the mixture of nitrous and atmoſpherical air. He was well aware of the cauſe of the increaſe of weight in calces, and diſtinctly aſſerted that certain baſes are rendered acid by the acceſſion of *nitro-atmoſpherical particles*, or what has ſince been called an acidifying principle. He diſcovered the method of producing factitious air, obſerved it's permanent elaſticity, and what is ſtill more ſtrange, the nice art of transferring it from veſſel to veſſel. The doctrine of reſpiration is all his own.

"If *Mayow* has not clearly expreſſed his opinions; if he uſes ſuch ambiguous expreſſions as require the aſſiſtance of modern diſcoveries to interpret them; if his experiments do not afford deciſive evidence; if he has not deduced the conſequences of his principles; then let the credit of one, who diſcovered far, and that by the light of his own genius, be withheld from him in as much as he has failed in any of theſe requiſites. I can

* Dr. Beddoes's Chemical Experiments and Opinions, extracted from a work publiſhed in the laſt century.

can just conceive it possible that a single important discovery may be made without much sagacity: an undiscerning eye may perhaps by chance be so placed, as to be aware of the manner in which nature performs some one of her hidden operations: but he who shall surprize her often, must be allowed to have the discerning eye, and to know where the proper point of view is to be found.

"Newton's discoveries concerning light, stand in the same predicament with Mayow's on air: both exhibit themselves as the greatest deviations, presented by the whole history of science, from the ordinary and natural progress of knowledge; they would undoubtedly (we see that it has actually happened in the one case) they would undoubtedly have been some time made, but not till a century or two had improved the talent, both of observation and of reflection; though our two illustrious countrymen, like the progenitor of mankind, when the archangel had purged his sight

"with euphrasy and rue,"

were, by a peculiar privilege, admitted to the view of scenes reserved for a distant posterity."

OF THE PNEUMATIC APPARATUS, AND OF THE METHOD OF MAKING EXPERIMENTS ON VARIOUS KINDS OF AIR.

The apparatus before you is sufficient for most of the experiments you will have occasion to make on the different kinds of air. It consists of a tub or trough of wood, with a shelf fixed therein: when you are using it, you must fill it with water, as you see it is at present, so as to rise rather more than an inch above the upper surface of the shelf. Several glass vessels or jars are placed with their mouth downwards on the shelf. See *fig.* 1, *pl.* 6.

I take

I take one of theſe jars, plunge it under the water, and then fill it therewith, and afterwards raiſe it with the mouth downwards, and place it on the ſhelf; it continues, as you ſee, full of water, and will do ſo as long as the mouth is immerſed therein; for in this caſe, the water is ſuſtained in the jar by the preſſure of the atmoſphere, in the ſame manner as the mercury in the barometer. From the Lectures on air, it muſt be evident to you, that if common air, or any fluid reſembling common air in lightneſs and elaſticity, be ſuffered to enter theſe veſſels, it will riſe to the upper part, and will depreſs and force out part of the water.

This glaſs cup is full of air; I plunge it into the water with the mouth downwards, and you obſerve that ſcarcely any water enters the cup, becauſe it's entrance is oppoſed by the elaſticity of the air; but if I turn the cup up it immediately fills, and the air riſes in ſeveral bubbles to the ſurface. I will now repeat the operation under one of theſe jars filled with water; the air aſcends as before, but inſtead of joining the common maſs, is detained in the upper part of the jar. In this manner *you may convey air from one veſſel into another by a kind of inverted pouring*, by which the air is made to aſcend from the lower to the upper veſſel. When the hole in the receiver is ſmall, I place this funnel inverted in one of the holes of the ſhelf, then put the neck of the receiver over that hole, and the air paſſing through the funnel enters the receiver as before.

Here is a glaſs bottle, *fig.* 2, the bottom of which is blown very thin, that it may ſupport the heat of a candle ſuddenly applied without cracking. In the neck is fitted a ground ſtopple, which forms the lower part of the bent tube. By means of the flexure of the tube, I can eaſily introduce the further end under one of the receivers, and by that means

means convey there any air that may be disengaged from the materials. I may put in the bottle *a*, *fig*. 1, *pl*. 6: of these I have several sizes for different purposes. Here is a small retort for the same purpose, the neck of which being plunged under one of the jars, the air extricated therein will be received in the jar.

Many elastic fluids combine with water, and therefore require an apparatus in which quicksilver is made use of; a marble trough is the most convenient for this purpose. You operate with mercury in this apparatus exactly as with water in the former; but the receivers used with it are smaller and stronger than those used with the water apparatus. (*fig*. 3 and 4, *pl*. 6.)

When any thing, as a small cup, &c. is to be supported at a considerable height within a jar, it is convenient to have a bent wire, which takes up but little room, and is easily fitted to any figure or height.

To expel air from solid substances by means of heat, a gun barrel, with the touch-hole screwed up and rivetted, is often used. The subject is put into the chamber of the barrel, and the rest of the bore is filled with dry sand that has been well burned, to expel any air it might contain. The stem of a tobacco pipe, or a small glass tube, is luted to the orifice of the barrel; the other end is put into the fire, that the air may be extricated from what it contains.

The most accurate method of procuring air from several substances, is to put them, if they will bear it, into phials full of quicksilver, and then throw the focus of a burning mirror or lens upon them.

To try whether air be fit for combustion, you may put the air into a long narrow vessel, whose mouth

mouth being carefully covered may be turned upwards; a piece of wax candle being then faſtened to the end of a wire, and ſo bent that the flame of the candle may be uppermoſt, is to be let down into the veſſel, which muſt be kept covered till the inſtant the lighted candle is plunged therein.*

When the change in dimenſions, which follows from the mixture of ſeveral kinds of air, is to be aſcertained, a gradual, narrow, cylindrical veſſel may be made uſe of. The graduations may be made by pouring in ſucceſſive equal meaſures of water into this veſſel, and marking it's ſurface at each addition. This meaſure may be afterwards uſed for different kinds of air, and the change of dimenſion will be ſhewn by the riſe or fall of the mercury in the graduated veſſel.

As the purity of common air is determined by the diminution produced by the addition of nitrous air, theſe tubes have been called *eudiometers.* There is an inſtrument alſo adapted for meaſuring with accuracy the change in bulk that ariſes from the mixture of theſe airs.

The air-pump is uſed for extracting the air from powders, and ſuch ſubſtances as cannot be conveniently put into a phial, or paſſed through a fluid.

To paſs the electric ſpark through different kinds of air, a metallic wire is faſtened to the upper end of a tube, and the ſparks or ſhocks are paſſed through this wire to the mercury or water uſed to confine the air; or two wires may be cemented in oppoſite holes in the ſide of an hermetically ſealed tube.

OF

* See Cavallo on air.
Nicholſon's Firſt Principles of Chemiſtry.
But above all, Dr. Prieſtley's Experiments and Obſervations on different Kinds of Air.

OF ELASTIC FLUIDS.

Elastic fluids are those which have acquired an aerial form, and which have the appearance of air; of these there are two kinds, those of gas or permanently elastic fluids, and those of vapour which are not permanently elastic.

Permanently elastic fluids, or gas, are those which have a great quantity of fire, so closely and intimately combined with the particles of the substance, as to preserve their elasticity in every known temperature. *Vapour*, or *not permanently elastic fluids*, are those, in which fire is not so closely combined, and which easily lose their elastic state by a change of temperature or density.

The various states under which you see bodies, depend almost entirely upon the different quantity, nature, and degree of their combination with fire. *Fluids* differ only from solids, because they possess at the common temperature of the atmosphere the quantity of fire which is requisite to maintain them in that state. They congeal or become solid with greater or less facility, according as they require a greater or less quantity of fire; so that bodies seem to possess three distinct quantities of fire:

1. A certain quantity which always resists the gravitating matter of the body, but which may be separated more or less: fire thus acting is called *sensible heat*.

2. The latent fire occasioning fluidity, by which the hardness or concreting powers of a body are overcome: this quantity is in some degree measurable, and might properly be called the *latent fire of fluidity*.

3. A certain quantity of fire, by which, under certain conditions, fluids, &c. may be rendered elastic: this may be called the *latent fire of elasticity*.

An

An elaſtic aeriform fluid, or gas, is then a peculiar combination of fire with a given ſubſtance. To reduce a ſubſtance to the gaſeous or aeriform ſtate, conſiſts in diſſolving it in fire, and thereby uniting it with an unknown ſubſtance, from which union it acquires it's peculiar qualities. Whenever gas is formed, there is an abſorption of fire; and reciprocally whenever gas paſſes into the ſolid or fluid ſtate, the portion of fire neceſſary to conſtitute the ſtate of gas appears again and is ſet at liberty.

Fire exiſts in every ſolid body; but the ſame body contains more fire in the liquid than in the ſolid ſtate, and ſtill more when it paſſes into an aeriform ſtate. It is therefore neceſſary to diſtinguiſh in every ſpecies of gas the *fire* which acts as a ſolvent, and the *ſubſtance* which is united to it, and ſerves as a baſe.

It is evident that fire eaſily combines with ſome ſubſtances. I have already ſhewn you, that there are ſeveral that at the temperature of the atmoſphere are conſtantly in the ſtate of vapour. There are others which require higher degrees, in order to acquire this ſtate.

In the firſt ſtate, or that of vapour, they ſoon loſe the fire which raiſed them, and return to their original form the moment the fire finds colder bodies to combine with. In the ſecond, or that of gas, the fire is ſo combined with the volatilized ſubſtance, that the ordinary temperature of the atmoſphere is not ſufficient to overcome the union.

Permanently elaſtic fluids are all compreſſible, tranſparent, colourleſs, inviſible, and not condenſable by cold. Some exiſt in nature without the aid of art; they may alſo be obtained by artificial means. Others are only procured by artificial means; ſome combine eaſily with water, others do not; ſo that different methods muſt be uſed to procure

cure them, according to the nature of the fluid you wiſh to obtain.

It will be neceſſary before I proceed to point out a few among the errors contained in M. Lavoiſier's "Elements of Chemiſtry;" errors which are highly prejudicial to true philoſophy, and which ſhew, that however excellent he may be as a chemiſt, he muſt not be taken as a guide in philoſophy, as you will eaſily perceive by conſidering his introduction to the Elements of Chemiſtry; for you will there find him affirming, "that water raiſed to the temperature of 212 is changed into *vapour, gas*, or an *aeriform fluid*." By uſing theſe words as ſynonymous, he introduces the utmoſt confuſion into philoſophy.

The vapour or ſteam of boiling water is undoubtedly an *expanſible fluid*, but it belongs to that genus of theſe fluids which is deſtroyed by *preſſure* and by *cold*. Now *gas* or *aeriform fluids* reſiſt both the one and the other of theſe cauſes, and are therefore often named *permanently elaſtic fluids*. This diſtinction, which is inconteſtable, cannot be neglected without producing great errors.

From hence you may deduce another error of Mr. Lavoiſier's, namely, where he aſſerts, "that all bodies are either ſolid or liquid, or in the ſtate of an elaſtic aeriform vapour, according to the relation which exiſts between the *attractive* force of their molecules, and the *repulſive* force of heat;" for, on the contrary, there are no known bodies to which this ſtatement applies. Again he affirms, "that if only theſe two forces exiſted, bodies would become liquid at an indiviſible degree of the thermometer, and would paſs inſtantaneouſly from ſolidity to aeriform fluidity; thus water, for inſtance, the very moment when it ceaſes to be ice, would begin to boil, and would be transformed into an aeriform fluid."——"That this does not

 happen,

happen, depends upon the action of a third force, the pressure of the atmosphere."

Mr. Lavoisier falls into two errors here, first, by considering the steam of boiling water as an aeriform fluid; secondly, by supposing that there is no other union of fire and water in an expansive form, but when the fluid product is sufficiently dense to counterballance by itself the pressure of the atmosphere. Whereas it is evident, from all phenomena and experiments, that aqueous vapour is formed in open air at every temperature, and mixes with the air without being destroyed by it's pressure. The same also takes place with other fluids of the same kind.

To prove this theory of the production of *aeriform* fluids by the simple union of fire to a liquid, when not counteracted by the pressure of the atmosphere, Mr. L. cites those expansible fluids which are formed in vacuo at the ordinary temperature of the atmosphere, as by ether, alcohol, water, and mercury; and he gives to all these mere products of evaporation, the name of aeriform fluids, though neither of them will resist cold or a strong pressure. But besides, these same *liquids evaporate*, under the pressure of the atmosphere as well as in vacuo, there being no difference in the two cases, but in the *time* employed to evaporate the same mass. In vacuo nothing opposes the actions of fire, first in detaching and then in separating to a certain distance the particles from the surface of the fluid: the air resists both these effects, and thus retards the operation: but the difference influences only as to time, for the laws of evaporation are the same in vacuo as in open air.

Each particular kind of vapour has a mechanism peculiar to itself, resulting from the *velocity* that fire preserves amongst it's particles, and the *mass* of the substance with which it is connected.

 Thus

Thus with particles of the ſame maſs, the greater the velocity of fire in any kind of vapour, the greater will be the expanſive force of the vapour. There is another law of evaporating liquids to be attended to, namely, that different kinds will be more or leſs denſe at the ſame temperature, and thus there may be different maximums for each, or diſtances at which their particles will unite: for the limits of denſity in vapour ariſe from the tendency of the particles to unite when they are at a certain diſtance. Theſe laws are exerciſed in open air, as in vacuo, and vice verſa.

Mr. Lavoiſier has been led into theſe errors by attending principally to the regular diminution of the degree of heat at which *liquids boil*, in proportion as there is leſs incumbent preſſure on their ſurface. Now ebullition is only an accidental phenomenon, which enters for nothing in the fundamental theory of vapours. For if we could expel all the air that is contained in liquids, they would *never boil*, neither in vacuo nor in air, and would then only evaporate at their naked ſurface. The evaporation would indeed be ſlower, but ſtill under the ſame laws, and would acquire at the ſame temperature an equal denſity with the vapours ariſing by ebullition from liquids not purged of air. For the degree of heat at which a liquid *boils*, is that where it's vapours are capable of ſupporting alone the incumbent preſſure, and which are formed in the boſom of the fluid as ſoon as there is any ſolution of continuity.

All liquids evaporate in open air, and their products (vapours) are ſubject to the ſame laws as if no air exiſted; but no known liquid can alone form an atmoſphere as denſe as our's, at leaſt ſo long as the vapours do not change their ſtate, for as ſoon as they get above a certain degree of denſity, they are deſtroyed by the preſſure of the ſu-

perior ſtrata. Whereas an aeriform fluid may compoſe an atmoſphere without limits, for we know of no degrees of preſſure that will deſtroy theſe fluids.

Hence you ſee how M. Lavoiſier errs, when he affirms, "That the views he has taken of the formation of aeriform elaſtic fluids, or gas, throws great light on the original formation of the atmoſpheres of the planets, particularly that of our earth; for we readily conceive that this muſt conſiſt of all the ſubſtances capable of being evaporated, or rather of remaining in an aeriform ſtate at the temperature of our atmoſphere, and under a preſſure equal to that of a column of quickſilver in the barometer 28 inches high." Now *real aeriform fluids* ſubſiſt at every degree of known *preſſure*, and at every *temperature*; but of vapours there are none known which can alone ſupport the total preſſure of the atmoſphere at it's uſual temperature with us. Thus you ſee how one ſmall error leads to others, and how readily a falſe principle is adopted to regulate the ſyſtem of nature by thoſe who love to indulge in ſpeculation.

Expanſible fluids are become, and with reaſon, one of the moſt intereſting objects for a natural philoſopher, as their compoſition and decompoſition is connected with the greater part of thoſe phenomena that are daily preſented for obſervation. This part of phyſical knowledge was very little known before our own time; by the diſcovery thereof, ſcience has been eſſentially promoted. We ſhould, however, be careful not to be ſeduced by novelty, nor ſuffer a pleaſing proſpect to make us neglect the fields already cultivated.

M. Lavoiſier ſtill proceeds to heap error on error. "To fix (ſays he) our ideas on this ſubject, conſider what would have happened to the various ſubſtances of our globe, if it's temperature were ſuddenly

ſuddenly altered; if the earth were ſuddenly tranſported into a very cold region, the *air*, or at leaſt ſome of the *aeriform fluids* which compoſe it, would ceaſe to exiſt in the ſtate of *elaſtic vapours*; for want of a ſufficient degree of heat they would return to their *liquid ſtate*, and *new liquids* would be formed, of which we have at preſent no idea." In this extract you find the ſame confuſion of terms as runs through the whole of this part of his treatiſe; hence alſo a confuſion of phyſical notions: for we know of no *aeriform fluid* that is deſtroyed by *cold*, nor is there any reaſon to ſuppoſe that there are any fluids of this kind, that by being deprived only of *fire* are converted into *liquids*. With reſpect to *vapours*, properly ſo called, we know of none, (although there are many kinds in our atmoſphere,) but the aqueous, of which the decompoſition produces a *liquid*.

The ſame confuſion affects other parts of his work; we find him inferring from the two oppoſite ſuppoſitions of extreme heat and extreme cold, "that ſolidity, liquidity, and elaſticity, are only three different ſtates of the ſame matter, three particular modifications through which almoſt all ſubſtances may ſucceſſively paſs, and which *ſolely depend on the degree of heat*." Theſe aſſertions involve all our phyſical knowledge in obſcurity. Now I know of no ſubſtance but *ice* and *metals*, which paſs from a ſolid ſtate to that of a liquid by the addition of fire alone.

For thoſe, which even in appearance are fuſible alone, are not ſo in the ſame manner after being cooled, as they were before fuſion; which proves in general, that the fuſion of theſe ſubſtances does not proceed from the operation alone of fire, but from certain chemical combinations put in action by fire.

Nor is there any known ſubſtance which paſſes from

from a liquid to an aeriform ſtate by the addition of fire alone. Indeed this change is ſtill myſterious, and ſeveral links are ſtill wanting in the chain, in order to unite it to our preſent knowledge.

Fire is without doubt the cauſe of the *expanſion* of every phyſical ſubſtance; but there is none that we are acquainted with, which by the change of *fire* alone paſs from an *aeriform* ſtate into ſuch a one as it was known to us when in a *concrete* form, water excepted. Every air that we produce, whether by the application of heat to certain ſubſtances, or by mixture, all leave a reſiduum, and always differ from the ſubſtances originally employed. The general means of learning what part of theſe ſubſtances paſſes into the aerial ſtate, is by a comparative analyſis of the ſubſtance itſelf, and the ſenſible product therefrom, *air* and the *reſiduum*; but whoever conſiders ſcrupulouſly theſe analyſes, muſt acknowledge that they are too imperfect to ſerve for the foundation of an hypotheſis.

Among the various hypotheſes, the following is that which includes the greateſt variety of caſes, and is of courſe the moſt extenſive in it's application; namely, that whatever ſubſtance is employed to produce air, *water* enters as a conſtituent part of that air; that water forms the *ponderable* or *gravitating* part of every aeriform fluid; that though *fire* be the immediate cauſe of their aeriform expanſibility, yet it does not in this caſe act as the fire of dilatation. But further, there is alſo ſome ſubſtance *without weight* which contributes to their union, and which forms the diſtinguiſhing characteriſtic of every ſpecies of air.

From hence it follows, that to decompoſe any air, it muſt be deprived of that ſpecific ſubſtance which is the medium between the water and the fire. The nature of the air may be changed, without

out losing it's aeriform existence, if this intermediate substance be changed or altered.

Fire, when communicated to water, forms an expansible fluid, but not one that is *permanently elastic*. It is *vapour* or *steam* that may be decomposed by compression or cold: but with the addition only of *light* to these two substances, an aeriform fluid is formed, as has been shewn by Dr. Priestley. M. de Luc also, in the course of his curious experiments on hygrometry, observed, that the heat of the room never produced any air from a vessel full of water therein, but that as soon as it received the incident rays of the sun, bubbles of air were formed, and continued to be formed as long as the light fell upon it. There is in water always a sufficient quantity of fire for the production of vapour, but this is not sufficient for the purpose of the abovementioned phenomenon; for vapour cannot be produced in the midst of water in the ordinary temperature of the air, the production thereof is prevented by the pressure of the atmosphere; but if *light* intervenes in sufficient quantity, it combines with the fire and the water, and instead of *vapour* produces an *aeriform fluid*.

From what hath been already said, as well as from what will appear on a further review of the subject, I think we may venture to assert, that the following propositions of M. de Luc give the clearest account of aeriform fluids, are more agreeable to observation, less liable to objection than any other view of the subject, and are more conformable to the best rules of physical reasoning.

1. That there is no instance of any substance passing into a *permanent aeriform state* merely by the addition of *fire*. 2. That *air* or *gas* differs from *aqueous vapour*, by the addition of some imponderable substance. 3. That *water* constitutes the *ponderable* part of all aeriform fluids: this

hypothesis is supported by a number of facts, contradicted by none, and throws great light on meteorology. 4. That it is the water of the airs or gasses which augments the weight of those substances to which they unite, and diminishes that of those from which they are disengaged. 5. That the substances peculiar to a certain species of aeriform fluids are the cause of acidity. 6. That *phlogiston*, a substance as imponderable as fire, is a substance that distinguishes every species of inflammable air; at a certain degree of *heat* it unites with vital air, and this union is the immediate cause of inflammation. 7. That besides phlogiston there exists in light inflammable air, another substance that distinguishes it from the whole class of heavier inflammable airs; a substance so associated with phlogiston as to prevent it's decomposing vital air, but changes it into aqueous vapour. 8. *Aqueous vapour* is a fluid consisting simply of water and fire; it is not permanently aeriform, because it may be reduced to it's original form by pressure or cold. 9. That aqueous vapour is easily decomposed, because it's union with fire is weak; if they were so strongly united as not to be separated, unless by some *chemical affinity*, the aqueous vapour would be changed into an aeriform fluid.

OF VITAL AIR.

This air was discovered by Dr. Priestley, though certainly known to Dr. Mayow, in the last century; it is a production of a most interesting nature to philosophy: it was first named dephlogisticated air. The French chemists consider it as consisting of a base called oxigene, combined with a great quantity of fire.

The supposed base has been called by the French *oxigene*, because they consider it as the true acidifying

acidifying principle, without which there would be no acid.

Reſpiration produces the ſame effect on air as combuſtion. When an animal is included in a limited quantity of atmoſpherical air, it dies as ſoon as the air is vitiated. Vital air, in ſimilar circumſtances, maintains the life of animals much longer than common air. Vegetables do not thrive in vital air.

No part of the atmoſphere exhibits this air in it's greateſt degree of purity; you will always find it combined, mixed, or altered by other ſubſtances. As it is combined with various ſubſtances, by decompoſition it may be eaſily extracted and procured.

Heat extricates it from a variety of ſubſtances, particularly from nitre, from allum, lapis calaminaris, and from the native calx of manganeſe, and from thoſe metallic calces which may be revivified without inflammable matter, as the calces of mercury precipitate per ſe, and the red precipitate, or mercury calcined by the nitrous acid; theſe furniſh it in great quantities, as you may readily aſſure yourſelves by the following experiment. I firſt put an ounce of red precipitate into this bottle, which is furniſhed with a ground ſtopple and bent tube, and then place it on a chafing diſh; as ſoon as the atmoſpheric air is all expelled by the heat, I tranſport the chafing diſh and bottle to my pneumatic tub, and put the bent tube under one of the receivers that are filled with water; in proportion as the mercury is revivified, you perceive that air paſſes through the tube, drives the water out of the receiver, and occupies it's ſpace; it is, as you may obſerve, tranſparent, colourleſs, and inviſible; and you will alſo find that it is elaſtic and compreſſible; in a word, you will find it to be pure, reſpirable, or vital air.

It

It may be obtained from minium, which is a calx of lead, when it is moiſtened with the nitrous acid: in this caſe it is the nitrous acid which furniſhes greateſt part of the vital air. All acids are connected with vital air; there are ſome which part with it eaſily. About 1200 cubic inches of vital air may be obtained from a pound of nitrous acid: nitre, with alkaline or earthy baſes, acetated mercury, and arſenicated zinc, afford this fluid in various quantities, by the action of light or heat. This fluid does not exiſt entire in any of theſe bodies; it is only as they contain nothing more than it's ponderable baſe, which is diſengaged and rendered an elaſtic fluid by the heat; for the metals can only be calcined by combining with the ponderable part of the air, which becomes ſolid in them, and adds to their weight. This is again expelled by heat, and combining with the fire, paſſes off in the form of an elaſtic fluid. During the operation, the metal loſing this ponderable part which had reduced it to a calx, recovers it's phlogiſton and metallic brilliancy, but loſes the weight it had gained by calcination.

Mr. Chaptal ſays, that a bottle of dephlogiſticated muriatic acid *expoſed to the ſun*, ſuffers all the ſuperabundant vital air to eſcape, and paſſes into the ſtate of the common muriatic acid. If the ſame acid be expoſed to the ſun, in a bottle wrapped in black paper, it does not ſuffer any change; and even when heated in a dark place, is reducible into gas, without being decompoſed.

The ſolar rays, when acting with any conſiderable energy, will alſo diſengage vital air from the calces of mercury, ſilver, and gold.

The marine ſalt of ſilver placed under water and *expoſed to the ſun*, gives out it's vital air; red precipitate, in ſimilar caſes, affords vital air, and does not require a long time before it becomes black.

black. You may alſo obtain vital air by means of the vitriolic acid. M. Chaptal uſed for this purpoſe the following ſimple proceſs. He put two ounces of manganeſe in a ſmall apothecary's phial, pouring thereon as much vitriolic acid as formed it into a liquid paſte; he fitted one end of a leg curved tube to the neck of the bottle, and let the other be inſerted under a receiver in the pneumatic tub, as in our former experiment, and then preſented a heated coal to the lower part of the bottle. The manganeſe he uſed was ſome he diſcovered at St. Jean de Gardonnenque, which affords vital air with great facility, nothing more being neceſſary for their purpoſe than to incorporate it with vitriolic acid. The firſt bubble is as pure as the laſt. Vital air diſcolours vegetable and animal ſubſtances: when abſorbed by fixed oils, it thickens them and reduces them into a ſtate reſembling wax.

We have already told you, that this pure and vital air is diſengaged from ſome ſubſtances, merely by the influence of ſolar light. You will ſoon ſee, that the influence of *light* on the operations of nature is exceedingly extenſive; and will be able, by a very eaſy ſet of experiments, to convince yourſelves of the nature of the proceſs.

Vital air continually emanates from vegetables expoſed to the light of the ſun: the leaves ſeem to elaborate this air by the means of light; the ſolar fluid is abſorbed, and becomes the cauſe of colour, flavour, &c. in the vegetable. In a word, it is fixed there as phlogiſton. The ſame operation enables the leaves of plants to emit the vital air. The emiſſion of vital air is proportioned to the vigour of the plant, and the vivacity of the light.

Dr. Prieſtley has ſhewn that plants have a power of correcting bad air, and Dr. Ingenhouſz that they have the faculty of elaborating the air they

they contain, and pouring down continually into the atmoſphere ſhowers of vital air, to render it more fit for animal life; and that this is entirely owing to the influence of the ſolar light on the plant. And I invite you to repeat his experiments when you are in the country in the ſummer ſeaſon, as they are eaſily made, and will afford you a very rational amuſement.

The proceſs for extracting this air from vegetables is exceeding ſimple: it conſiſts in immerſing or incloſing them in water, in an inverted glaſs veſſel filled therewith, and placed on the ſhelf of your pneumatic tub. The moment the plant is acted on by the ſun, you will obſerve ſmall bubbles of air formed on it's leaves, which gradually grow larger, and detaching themſelves from the fibres of the leaf, ariſe to the upper part of the veſſel, and diſplace the water.

All plants do not emit this air with the ſame facility; there are ſome which emit it the moment the ſun acts upon them, as the leaves of the jacobæa, of lavender, and ſome aromatic plants. Some aquatic plants ſeem alſo to excel in this operation; others emit it more ſlowly, but none later than 8 or 10 minutes, provided the ſun's light be ſtrong. The air is almoſt totally furniſhed by the inferior ſurface of the leaves of trees; herbaceous plants afford it from almoſt the whole of their ſurface. The leaves afford more air when attached to the plant, than when gathered; and the quantity is greater, the freſher and ſounder they are. Young leaves afford but a ſmall quantity of vital air, thoſe which are full grown afford more, and the more the greener they are; for it is not produced by leaves which are injured or yellow. The parenchyma of the leaf appears to be the part which emits the air. The epidermis, the bark, and the white petals, do not afford it; and in general, vital air

air is only furniſhed by the green parts of plants. Thus alſo green fruits and grain afford this air; but it is not furniſhed by thoſe which are ripe; and flowers in general render the air noxious.

M. Chaptal mentions having often collected this air, and that in abundance, from a kind of moſs, which covers the bottom of a veſſel filled with water, and ſo well defended that the ſun never ſhone directly upon it.

Dr. Ingenhouſz obſerves, that the conferva, as well as the green matter which is formed on water, affords much vital air. M. Senebier has ſhewn, that an acid diluted in water increaſes the quantity of air which is diſengaged, (when the water is not too much acidulated,) and in this caſe the acid is decompoſed.

Water plants, it has been obſerved to you, are remarkably vigorous in this property of yielding vital air, and thus correct the inflammable air bred by the ſoil in low marſhy grounds; ſo that theſe places produce one of the beſt remedies for their own natural evils: and thus do all things work together for good.

The plant of the *naſturtium Indicum*, in the ſpace of two hours, gives out more pure air than equals the bulk of all it's leaves: what a quantity then muſt be diſcharged from lofty trees in a day's time. Does not this point out an error in the modern practice of leaving dwelling-houſes ſo naked to a conſiderable diſtance, and deſtitute of vegetation.

The act of vegetation alone is not ſufficient to produce this ſalutary effect upon the air: it is vegetation in the ſun-ſhine from whence this good is to be expected.

The ſun does not act merely from it's heat: the emiſſion of this gas is occaſioned by the light, and may therefore be obtained by a ſtrong light, without

without the direct action of the solar rays; the excretion is stronger as the light is more vivid. It would seem as if light favoured the work of digestion in the plant, and that the vital air, which is one of the principles of almost all the nutritive juices, more especially of water, is emitted, when it finds no substance to combine with in the vegetable. Hence it arises, that plants, whose vegetation is the most vigorous, afford the greatest quantity of air.

Dr. Ingenhousz, since the publication of his English work on vegetables exposed to the light of the sun, has been more or less constantly employed on the same subject; and on occasion of some controversies, has published, both in French and German, many experiments, all tending to the same conclusion. His chief controversy was with Mr. Senebier of Geneva, which, however, has terminated completely in his favour; for his antagonist has candidly acknowledged that he was totally misled by some inattention in conducting his processes. In the Acta Theodoro-Palatina is a very long series of experiments by professor Succow of Mannheim, which exactly coincide with those of Dr. Ingenhousz.

He concludes his account of them in the following manner. "Those effects of the solar light on plants, which Dr. Ingenhousz first so admirably pointed out, are confirmed by the preceding experiments, in which trees and plants appeared most capable of yielding pure air in the light of the sun; whereas in the shade they afforded air more or less phlogisticated. That the air which is extricated when vegetables are exposed in water to the sunshine, proceeds from their leaves and other parts, scarce needs any proof. Water indeed does contain a quantity of air which is disengaged by the influence of light; but the quantity is so sparing

even

even in a large quantity of water, that it can by no means be ſet in competition with that which vegetables yield in the courſe of a few hours. Did this air proceed from the water, it would in a very few caſes prove ſo pure, unleſs the water contained ſome of the *green conferva;* but then it would be to *this moſs* that the origin of the air muſt be aſcribed. The difference in the air itſelf, which vegetables yield when other circumſtances are alike, puts it beyond all doubt, that the air proceeds not from the water, but the vegetables."

Dr. Ingenhouſz, in his laſt work, has related ſome variations of his experiments. He found that water impregnated with acids, alkalies, neutral ſalts, expreſſed juices of vegetables, as of raiſins, peaches, &c. very much promoted the production of pure air by vegetables, except in the caſe of the graſſes (of which the product is variable from undiſcovered cauſes), of the conferva rivularis, and water-plants in general, which are killed by fixed air, and ſome others, when this acid is employed. A few ſubſtances, ſuch as the juice of onions, cucumbers, and turneps, prevented, inſtead of forwarding, the extrication of air.

Among the ſubſtances which favour the extrication of pure air, we have every thing which can well be ſuppoſed to enter into the compoſition of manure, ſalts ſimple and compound, with the juices and extractive matter of plants. If we may aſſume, that the production of this ſalutary fluid is a natural function and an healthy proceſs, it follows directly, that the *uſe of manure* is to occaſion *a greater exertion of that function.*

That the production of vital air is among the chief functions of vegetables, is a ſuppoſition countenanced by many experiments. Mr. Cavendiſh himſelf infers, that the vital air obtained by Dr. Ingenhouſz comes from the decompoſition of wa-

ter.

ter. There is one experiment related by the laſt-mentioned author, highly remarkable, and not to be explained on any other ſuppoſition that has been hitherto thrown out. "I boiled (ſays he) ſome water for two hours, and then poured it boiling into a glaſs balloon of the capacity of 200 cubic inches. The balloon was then carefully cloſed. Before the water was grown quite cold, I introduced into the balloon four cubic inches of granulated green matter, which was taken out of the great reſervoir in the botanic garden (at Vienna), and repeatedly waſhed in boiling water; care being taken to ſqueeze out after each waſhing all the moiſture, in order that none except boiling water might remain adhering to it. I next cloſed the balloon with a perforated ſtopple, in order to allow the water an exit when it ſhould be preſſed by the air evolved from the green matter. The balloon was inverted into a veſſel of quickſilver placed in the ſun. The air generated at firſt was abſorbed by the water itſelf: but being ſoon ſaturated, it refuſed to take up any more; and in the courſe of a few days I found a conſiderable quantity of air collected." If then it be true that water is decompounded by vegetables, it follows that inflammable air or *phlogiſton* is abſorbed and fixed; an opinion countenanced by Prieſtley's experiments on charcoal, on ſliced roots of onions, &c. for neither he nor Senebier, nor Ingenhouſz, nor I think any other, has ever found inflammable air in the elaſtic fluid afforded by the leaves and other proper parts of vegetables expoſed to the ſun. The inflammable matter which ſurrounds certain vegetables is, I ſuppoſe, an eſſential oil in the ſtate of vapour; and if any plant ſhould yield inflammable air in the way I have mentioned, I doubt not but it would furniſh, in other reſpects as well as this, a ſingular exception to the reſt of the kingdom.

There

There is ſtill another corollary more preciſe and ſatisfactory to be drawn from theſe premiſes. The quantity of vital air that is extricated, will afford a teſt of the quantity of food taken in the plant.

It may, moreover, be ſuppoſed, that the additions, which Dr. Ingenhouſz made uſe of, are not thoſe which will produce the greateſt effect. It is reaſonable to ſuppoſe, that Nature, in the immenſity of her ſtores, has ſtimulants far exceeding theſe in power; which further inquiry will both diſcover and teach how to apply. For if theſe principles be juſt, they will be eaſily applicable, when we are in poſſeſſion of a greater number of facts, both to gardening and agriculture: and I doubt not but that in time a rational ſyſtem of vegetable medicine may be conſtructed, if the ſubject be properly proſecuted. In the mean time, languiſhing trees may be waſhed or ſprinkled with water acidulated with vitriolic acid, which Ingenhouſz found to be moſt effectual in promoting the production of pure air.

It will not be difficult for any perſon, who may chooſe to reflect on the ſubject, to contrive other experiments, by which theſe principles may be confirmed or refuted.

This vital air from plants is a *beneficent gift from God*, to repair inceſſantly the conſumption thereof in the œconomy of nature. The plant abſorbs atmoſpherical mephitis, and emits vital air. Man on the contrary is kept alive by vital air, and emits much mephitis. The animal and vegetable kingdoms therefore *labour for each other*. By this admirable reciprocity of ſervices, the atmoſphere is continually repaired, and an equilibrium maintained between it's conſtituent principles.

From theſe diſcoveries, ſays Sir J. Pringle,

we are aſſured, that no vegetable grows in vain; but that from the oak of the foreſt to the graſs of the field, every individual plant is ſerviceable to mankind; if not always diſtinguiſhed by ſome private virtue, yet making a part of the whole, which cleanſes and purifies our atmoſphere. In this the fragrant roſe and deadly night-ſhade co-operate: nor is the herbage, nor the woods that flouriſh in the moſt remote and unpeopled regions, unprofitable to us, nor we to them, conſidering how conſtantly the winds convey to them our vitiated air for our relief, and their nouriſhment. And if ever theſe ſalutary gales riſe to ſtorms and hurricanes, let us ſtill trace and revere the ways of a beneficent Being, who not fortuitouſly, but with deſign, not in *wrath*, but in *mercy*, thus ſhakes the waters of the earth together, to bury in the deep thoſe putrid and peſtilential effluvia, which the vegetables upon the face of the earth had been inſufficient to conſume.

The properties of vital air are more or leſs ſtriking, according to it's degree of purity. This depends in general upon the ſubſtances from which it is produced. That obtained from mercurial calces generally holds a ſmall quantity of mercury in ſolution. M. Chaptal mentions it having ſpeedily ſalivated two perſons who uſed it for diſorders in the lungs; and alſo that having filled bottles with the air, and then expoſed them to an intenſe cold, the ſides became obſcured with a ſtratum of mercurial calx, in a ſtate of extreme diviſion: that having heated the bath, over which he cauſed this air to paſs, he obtained at two different times yellow precipitate. The air obtained from plants is not equally pure with that afforded by the metallic calces.

Vital air is heavier than atmoſpheric air. A cubic foot of atmoſpheric air weighs 720 grains; a cubic

a cubic foot of vital air 765 grains. Mr. Kirwan makes it's weight to that of common air, as 1103 to 1000.

Several of the metals, when diſſolved in ſpirit of nitre, afford, by an efferveſcence, a kind of air called nitrous air, of which I ſhall ſpeak hereafter. If this air be mixed with any other elaſtic fluid which contains vital air, it unites with this laſt, and forms red fumes, which fall down, and are found to conſiſt of nitrous acid; the air is diminiſhed in bulk by the loſs, and hence the nitrous air becomes a teſt of the goodneſs of reſpirable air.

Vital air is the only fluid proper for combuſtion: for when bodies burn in common air, it is only the vital air contained therein which aſſiſts combuſtion. When the vital air is pure and diſengaged from other fluids, there is great increaſe of heat and light during the combuſtion. Theſe two phenomena are occaſioned by the rapid ſeparation of the fire, which is diſengaged from the body and from the vital air. It appears from experiment, 1. That there is no combuſtion without vital air. 2. That in every combuſtion there is an abſorption of vital air. 3. That there is an augmentation of weight in the products of combuſtion, ſaid to be equal to the weight of the vital air that is abſorbed. 4. In all combuſtion, heat and light are diſengaged.

I plunge a lighted taper into one of theſe veſſels filled with vital air; the flame you ſee becomes inſtantaneouſly more ardent, more lively, more luminous, while the combuſtion is four times more rapid.

Here is a bit of wood, one end of which has been charred; I light it, and then plunge it into this bottle of vital air; the wood you ſee inflames immediately, and burns away with aſtoniſhing rapidity.

pidity. You remember Dr. Ingenhoufz's brilliant experiment, when we burnt the iron wire in vital air.

Mr. Lavoifier prepared an apparatus proper to afcertain the quantity of vital air introduced into it; and alfo what was confumed during the experiment; fome phofphorus was placed in this apparatus; when the whole was properly difpofed, he fet fire to the phofphorus with a burning glafs, the combuftion was extremely rapid, accompanied with a bright flame and much heat. As the operation went on, large quantities of white flakes attached themfelves to the inner furface of the globe, fo that at laft it was rendered quite opake. The quantity of thefe flakes became fo abundant, that although frefh vital air was continually fupplied, which ought to have fupported the combuftion, yet the phofphorus was foon extinguifhed.

The apparatus being completely cooled, he firft afcertained the quantity of vital air employed, and weighed the balloon accurately before it was opened. He then wafhed, dried, and weighed, the fmall quantity of phofphorus that remained in the cup; this refiduum was of a yellow ochrey colour. By thefe feveral precautions he determined, 1ft. The weight of the phofphorus. 2. The weight of the flakes produced by the combuftion. 3. The weight of the vital air combined with the phofphorus. The refult fhewed, 1ft. That the phofphorus, during it's combuftion, had abforbed rather more than one and a half it's weight from vital air. 2. That the weight of new fubftances produced, exactly equalled the fum of the weights of the phofphorus confumed, and the vital air employed.

You have been told, that phofphorus is changed by combuftion into an extremely light, white, flakey matter; the properties are entirely altered by the transformation. From being infoluble

luble in water, it is now not only ſolvible therein, but ſo greedy of moiſture as to diſengage the humidity from the air with aſtoniſhing rapidity, by which it is converted into a liquid more denſe, and of greater ſpecific gravity than water. The phoſphorus before combuſtion had ſcarcely any ſenſible taſte; by it's union with vital air, it acquires an extremely *ſharp* and *ſour* taſte; in a word, from the claſs of combuſtible bodies, it is changed into an incombuſtible ſubſtance, and becomes one of thoſe bodies called *acids*.

Many other combuſtible ſubſtances are alſo thus converted into acids by the addition of vital air. The French writers, therefore, term every combination of vital air with a combuſtible ſubſtance, *oxygenation*.

Sulphur is a combuſtible ſubſtance, or in other words, it is a body which poſſeſſes a power of decompoſing vital air by ſeparating from it the fire with which it was combined This is eaſily proved by experiments ſimilar to the preceding, though the reſults cannot be obtained with the ſame accuracy; becauſe the acid formed by the combuſtion is not eaſily condenſed, becauſe ſulphur does not burn ſo eaſily as the phoſphorus, and is ſoluble by different gaſſes. Mr. Lavoiſier ſays, that notwithſtanding this, he can affirm from his own experiments, that ſulphur in burning abſorbs vital air (or more accurately the water therein); that the reſulting acid is conſiderably *heavier* than the ſulphur burnt; that it's weight is equal to the ſum of the weights of the ſulphur, which has been burnt, and of the vital air which has been abſorbed; and laſtly, that this acid is weighty, incombuſtible, and miſcible with water in all proportions.

Charcoal decompoſes alſo vital air, by abſorbing the baſe from the fire; the acid reſulting from this combuſtion, is not condenſible in the com-

mon temperature and pressure of our atmosphere, it remains in the state of gas, and requires a large portion of water to be combined with or be dissolved in. It has however the properties of all other acids, though in a weaker degree. This aeriform acid was called *fixed* or *fixable air*, by the chemist who first discovered some of it's properties.

Mr. Lavoisier affirms, that it is easy to prove *that all acids are formed by the combustion of certain substances*; that the ponderable part of vital air is an element common to them all; and that from many acids vital air may be easily obtained.

Vital air is separated from it's fire by metals, when heated to a certain degree; in consequence of which all metallic bodies, excepting gold, silver, and platina, have the property of decomposing vital air, and attracting the base * from the fire with which it was combined. We have already shewn you, in what manner this decomposition takes place, by means of mercury and iron: the first is a very gradual combustion; the latter is very rapid, and attended with a very brilliant flame. The heat employed in these operations, is to separate their particles, and loosen their cohesion.

The absolute weight of metallic substances is augmented in proportion to the quantity of vital air they absorb; they lose at the same time their metallic brilliancy, and are reduced into an earthy pulverizable matter.

The metals do not act so powerfully in vital air as to separate it entirely from it's fire, which is supposed to be the reason that they are not converted into acids like sulphur, phosphorus, and charcoal, but into an intermediate substance, which, though approaching the nature of salts, has not acquired all the saline properties. The old chemists affix the

* The ponderable base is water.

the name of calx to metals in this ſtate; the French chemiſts have ſubſtituted in it's room the word *oxyd.*

Vital air is ſaid to form almoſt a third part of the maſs of our atmoſphere, and is conſequently one of the moſt plentiful ſubſtances in nature. All animals and vegetables live and grow in this immenſe magazine of vital air, and from it is procured the greater part of what is employed in experiments. So great is the affinity of this element and other ſubſtances, that it cannot be procured free from all combination.

To oxygenate a ſubſtance, or make it combine with vital air, it is neceſſary that the parts of the ſubſtance ſhould have more affinity with vital air than to each other. This may, in ſome degree, be brought about by art; for by heating them, or by introducing fire into their interſtices, we diminiſh the coheſion of the particles. The degree of heat at which the oxygenation takes place, is different in different bodies. Many bodies combine with vital air by being expoſed to the air of the atmoſphere, in a convenient degree of temperature. With reſpect to lead, mercury, and tin, this need be but little higher than the medium temperature of the earth; but iron and copper, when the operation is not aſſiſted by moiſture, require a much greater degree of heat.

Oxygenation ſometimes takes place with great rapidity, and is accompanied with great ſenſible heat, light, and flame; ſuch is the combuſtion of phoſphorus in atmoſpheric air, and of iron in vital air. That of ſulphur is leſs rapid, while that of lead, tin, and moſt of the metals, is affected very ſlowly; and conſequently the diſengagement of fire, and more eſpecially of light, is hardly ſenſible.

The affinity of ſome ſubſtances with vital air, is ſo ſtrong, and they combine with it at ſuch low

degrees of temperature, that we cannot procure them in their unoxygenated ſtate; ſuch is the muriatic acid. There are other means of combining ſimple ſubſtances with vital air; for a knowledge of which, I muſt, however, refer to the writings of Lavoiſier, Morveau, &c.

Vital air is peculiarly neceſſary for reſpiration; animals live a much longer time in it, than they would in the ſame quantity of atmoſpheric air.

Count Morozzo placed ſucceſſively ſeveral full grown ſparrows under a glaſs receiver inverted over water. It was filled with atmoſpherical air, and afterwards with vital air. He found,

1ſt. That in atmoſpherical air		*Hours.*	*Min.*
The firſt ſparrow lived		3	0
The ſecond,	—	0	3
The third,	—	0	1

The water roſe in the veſſels eight lines during the life of the firſt, four during the life of the ſecond, and the third produced no abſorption.

2. In vital air,		*Hours.*	*Min.*
The firſt ſparrow lived,		5	23
The ſecond,	—	2	10
The third,	—	1	30
The fourth,	—	1	10
The fifth,	—	0	30
The ſixth,	—	0	47
The ſeventh,	—	0	27
The eighth,	—	0	30
The ninth,	—	0	22
The tenth,		0	21

From theſe experiments we may conclude, 1. That an animal lives longer in vital than in atmoſpherical air. 2. That one animal can live in air, in which another has died. 3. That, independent of air, ſome reſpect muſt be had to the conſtitution of the animal: the ſixth lived 47 minutes, the fifth

fifth only thirty. 4. That there is either an absorption of air, or the production of a new kind of air which is absorbed by the water as it rises.

Vital air is therefore the fluid proper to support the life of animals. A great quantity of fire is necessary to support life. Vital air combines readily with the mephitis in the blood and lungs; and thus a part of it's fire is set at liberty, which goes to the support of life. The other part combines with the mephitis, and forms what is called azotic gas, or phlogisticated air. It is the affinity between the mephitic and vital air, which constitutes the fitness of vital air for respiration; the bases of no other elastic fluid possess the same property. Vital air answers two purposes, which are both equally necessary for our preservation. It takes from the blood it's superabundant mephitis, which would be prejudicial, and gives out fire to support the continual waste thereof, to which our frame is liable.

It has long been known, that animals cannot live without the assistance of air. Though the phenomena of respiration have been very imperfectly known until lately, the ancients are those who had the more accurate ideas concerning it. They admitted in the air a principle proper to nourish and support life, which they denoted by the name of *pabulum vitæ*.

They also knew that there was a striking relation between the flame of a candle and the principle of life in an animal body. Physicians have also argued for what some of them have termed a *biolychnus* (candle of life) in the blood. Bartholine says, that animal fire is kept up in the heart by a reciprocal ventilation from the lungs, *as a common flame* is excited by the air from a pair of bellows; and that when this ventilation from the lungs ceases, life goes out as naturally as fire with-

out

out air. The ancients were alſo of an opinion, that part of the air drawn in by the lungs actually paſſes into the arteries; and the arteries are ſuppoſed to take their name from the air or ſpirit which they contain, together with the arterial blood.

The vapour emitted by expiration from the lungs is a mixture of phlogiſticated air, fixed air, and vital air. If the vapour iſſuing from the lungs be made to paſs through lime-water, it renders it turbid; if it be received through tincture of turnſole, it reddens it; and if an alkali be ſubſtituted to the turnſole, it becomes effervescent.

When the foregoing proceſs has abſorbed all the fixed air, the remainder conſiſts of phlogiſticated air and vital air. The preſence of vital air is manifeſted by means of nitrous air. The air, in which Mr. Chaptal had cauſed five ſparrows to periſh, afforded 1700 parts of vital air. The expired air being thus deprived of all it's vital and fixed air, the remainder was phlogiſticated air. Animals feeding upon herbs and grain, are ſaid to vitiate the air leſs than carnivorous animals.

A portion of air is abſorbed in reſpiration. Dr. Jurin ſays, that a man inſpires 40 cubic inches of air by his uſual exhalations; that in the greateſt he could receive 220 inches; but that a portion was always abſorbed. Dr. Hales conſidered the abſorption as taking up 136th part of the reſpired air. Now as a man reſpires 20 times in a minute, and inhales 40 cubic inches of air at each inſpiration, this makes 48,000 in an hour; which divided by 136, gives 353 inches of air abſorbed and deſtroyed in an hour. From more accurate experiments, M. de la Metherie concludes, that 360 cubic inches of vital air are abſorbed in an hour. Theſe facts ſhew how eaſily air, when it is not

not renewed, is vitiated by reſpiration, and why the air of theatres and cloſe crouded places is ſo unwholeſome.

A variety of facts prove that the vermilion colour aſſumed by the blood in the lungs ariſes from the vital air which combines with it, and is the firſt effect of the contact, abſorption, and combination of vital air with the blood. If blackiſh venous blood be expoſed in a pure atmoſphere, the ſurface becomes a vermilion colour; a fact daily obſerved when blood is expoſed in a porringer to the air. Air which has remained in contact with blood, extinguiſhes candles, and precipitates lime-water; air injected into a determinate portion of a vein, between two ligatures, renders the blood of a high colour. The blood which returns from the lungs, is of a higher colour. Hence ariſes the great intenſity of the colour of arterial blood compared with venous blood.

Mr. Thouvenel is ſaid to have ſhewn that by withdrawing the air which is in contact with the blood, it may again be made to loſe it's colour. Blood, expoſed in a vacuum, remained black, but it aſſumed a beautiful vermilion colour as ſoon as it was expoſed to air. Theſe, with various other facts, ſhew, that the vermilion colour of blood ariſes from air.

The ſecond effect of reſpiration is to eſtabliſh a focus of heat in the lungs; a circumſtance entirely oppoſed to the opinion of thoſe who conſidered the lungs merely as a kind of bellows, deſigned only to cool the human body.

The heat in each claſs of individual animals is proportioned to the magnitude of their lungs. Animals with cold blood have only one auricle and ventricle.

All perſons who have reſpired vital air, agree that it communicates a gentle vivifying heat to the lungs,

lungs, which infenfibly extends from the breaft to all other parts of the body.

The foregoing, and many other facts, unite in proving that a focus of heat really exifts in the lungs, which is maintained and kept up by the air of refpiration.

In fact, there is an abforption of vital air in refpiration. Refpiration is an operation, by means of which vital air paffes continually from an aerial to a concrete ftate, and confequently is continually quitting the fire by which it was fupported in a ftate of gas.

The heat produced at every infpiration feems therefore to depend on the volume of the lungs, their activity, the purity of the air, the rapidity, &c. of the infpirations.

More heat is confequently produced in winter, becaufe the air is more condenfed, and furnifhes more vital air under the fame bulk, and confequently more heat to the inhabitants of colder climates. Thus does a *benevolent Providence* continually temperate and ballance the cold of thefe climates.

M. Chaptal fays, that the lungs of afthmatic perfons are lefs capable of digefting this air, and that they emit air without vitiating it; from which caufe their complexion is cold, and their lungs continually languifhing: hence they find vital air peculiarly comfortable.

From what has been faid you muft have perceived, that the phenomena of *refpiration* are fimilar to thofe of combuftion. This has been eftablifhed by Dr. Crawford, who has clearly fhewn, that *animal heat* is one of the principal advantages derived from refpiration; that when the blood returns from all parts of the body to the lungs, it has loft a quantity of it's fire, and imbibed fome noxious quality; that in the lungs it meets with atmofpheric air; that it abforbs fire from the vital air contained

tained therein, and imparts to the air, which remains, it's impurity; that the blood having thus robbed the air contained in the lungs of a portion of it's fire, and rendered that which remained ſenſibly warm, the air is expelled, and freſh air taken in to undergo the ſame proceſs.

The quantity of air changed by a man, in a minute, is found to be equal to that which is altered by a candle in the ſame ſpace of time; and hence a man is continually deriving as much heat from the air as is produced by the burning of a candle.

Vital air has been uſed with ſucceſs in diſorders of the human frame. Meſſrs. Caillens and Chaptal ſpeak of it's having been reſpired in phthiſical diſorders with great ſucceſs. He is far, however, from conſidering it as a ſpecific, and is doubtful as to it's application; yet as it inſpires cheerfulneſs, and renders the patient happy, he conceives it to be an admirable remedy in deſperate caſes, as it will ſpread flowers as it were on the borders of the grave, and prepare us in the gentleſt manner for the laſt dreadful effort of natural life.

Or

OF PHLOGISTICATED AIR, AZOTIC GAS, OR ATMOSPHERICAL MEPHITIS.

This air is ſuppoſed to be from the mephitic part of the atmoſphere, or that part which is not fit for reſpiration. Dr. Prieſtley ſuppoſed it to be air altered by the phlogiſton diſengaged from bodies in combuſtion, or other phlogiſtic proceſſes. It is, however, now thought to exiſt ready formed in the atmoſphere, and to be the reſiduum thereof when this is deprived of it's vital air. Mr. Lavoiſier calls it azotic gas, from it's known property of killing ſuch animals as are forced to breathe in it. The word is derived from the Greek privitive particle α, and ζωη, life.

This element is always in a ſtate of gas in the ordinary preſſure and temperature of the atmoſphere, and no degree of cold or compreſſion has hitherto been capable of reducing it either to a ſolid or liquid form.

It is the reſidue of combuſtion, of the reſpiration of animals, and of putrifaction, becauſe in all theſe caſes vital air is abſorbed. In reſpiration, a portion of the fire from vital air goes to the ſupport of life, while the remainder combining with a part of the blood becomes fixed air, which is expired together with the phlogiſticated air.

This gas may be procured pure by ſeveral methods; that of Scheele is the one moſt generally uſed: it conſiſts in expoſing liver of ſulphur in a liquid ſtate to a given quantity of atmoſpheric air under a glaſs receiver; the ſulphur abſorbs by degrees the vital air, and when the abſorption is complete the phlogiſticated air remains pure. M. Berthollet obtained it from muſcular fleſh, or from the fibrous part of the globules of blood, by well waſhing it with nitrous acid in the pneumatic apparatus;

apparatus; for the baſe of this gas enters into the compoſition of fleſh, and ſerves to animalize it. The animal ſubſtances made uſe of muſt be freſh, for if they are altered by putrifaction, they furniſh fixed air mixed with the phlogiſticated gas. When by any other means, as the calcination of metals, the rancidity of oils, combuſtion, the vital air of the atmoſphere is abſorbed, the reſidue is this gas. M. Fourcroy has diſcovered, that the bladders of carp are full of it, and that it may be eaſily collected by breaking them underneath veſſels filled with water.

It is lighter than atmoſpheric air. When the barometer ſtands at 30.46, and the thermometer at 60, the weight of the phlogiſticated air is to that of common air as 985 to 1000. You may eaſily ſatisfy yourſelves that it is lighter than common air: for this purpoſe put three or four lighted tapers, of different heights, under this receiver full of common air, in which the air cannot be renewed, and you will obſerve that in proportion as the vital air is decompoſed, they go out, the higheſt firſt; a ſufficient proof that this gas forms the lighteſt part of the air.

Phlogiſticated air, when it is pure, has neither taſte nor ſmell.

It is not ſolvible in water, or only in a very ſmall degree.

I have divided a long glaſs tube into equal meaſures, which is diſtinguiſhed by marks made with a diamond. I ſhall now put two meaſures of phlogiſticated gas into this tube, and then agitate it ſtrongly in water; and you ſee that after the agitation the volume of air is not ſenſibly diminiſhed.

This gas does not exhibit any ſign of acidity; it does not redden the blue colour of vegetables. Here is a tube full of mere phlogiſticated air; I

 intro-

introduce therein a ſmall quantity of the tincture of turnſole, diluted in water, and you find that the colour remains the ſame, and is not changed by the gas.

Phlogiſticated air does not precipitate lime from lime-water. I put a ſmall quantity of lime-water into a tube filled with the gas, and you ſee that it remains clear and limpid, and that no precipitation takes place.

It is improper for reſpiration and combuſtion; an animal is ſoon ſuffocated therein, and a candle or taper immediately extinguiſhed.

Plants live and vegetate in this air, and render it reſpireable; the vegetables decompoſing the water, ſeparate the vital air from it, which mixing with this gas, forms atmoſpheric air; in fact, 72 parts of this gas mixed with 28 of vital air, forms air ſimilar to that of the atmoſphere.

This gas mixes with other airs without combining with them; it is abſorbed by nitrous acid, which renders it fuming. Mr. Cavendiſh has ſhewn, that 3 parts of azotic gas mixed with 7 of vital air, and then expoſed to the paſſage of the elaſtic ſpark, is gradually condenſed, and produces the *nitrous acid*.

Almoſt every air or gas is convertible into phlogiſticated air. *Vital air* abſorbed by charcoal which has been made red-hot, and expelled from thence by plunging the charcoal in water, is changed into phlogiſticated air. A mixture of one meaſure of *vital air* and two meaſures of inflammable air, kept ſtanding for ſome time together, was found to contain a quantity of phlogiſticated air. *Nitrous* is changed into phlogiſticated air by ſeveral methods, among others, by expoſure to the electric ſpark, by abſorption by charcoal, and expulſion from thence.

M. Berthollet has diſcovered, that it is a combination

bination of this air with inflammable air that forms the ammoniac obtained from animal ſubſtances, by the action of fire, and by putrifaction; and that plants, which give the ſame ſalt by diſtillation, furniſh it in conſequence of their containing this gas, and therefore well deſerve the name of *animal* plants, which has been given to them by ſome chemiſts. M. Fourcroy has found, 1. That of animal matters, the fibrous parts afford moſt of this gas by nitrous acid: when the nitrous acid acts upon the fleſh, or other parts of animal ſubſtances, the elaſtic fluid, which is firſt and moſt plentifully diſengaged, is phlogiſticated air. 2. That after putrifaction they contain no more phlogiſticated air, but are rendered capable of affording a conſiderable quantity of ammoniac.

OF ATMOSPHERIC AIR, AND IT'S DIVISION INTO TWO ELASTIC FLUIDS; ONE FIT FOR RESPIRATION, THE OTHER INCAPABLE OF BEING RESPIRED.

From the preceding Lectures it appears, that our atmoſphere is compoſed of a mixture of every ſubſtance capable of retaining the gaſeous or aeriform ſtate in the common temperature, and under the uſual preſſure; that theſe fluids conſtitute a maſs in ſome meaſure homogeneous, extending from the ſurface of the earth to the greateſt height hitherto attained, and whoſe denſity continually increaſes in the inverſe ratio of the ſuperincumbent weight: but it is poſſible that this firſt ſtratum may be ſurmounted by ſeveral others conſiſting of different fluids.

Modern chemiſts have endeavoured to determine by experiments the elaſtic fluids which compoſe the lower ſtratum we inhabit. There are two methods of determining the conſtituent parts of

bodies, the method of *analyſis*, and that of *ſyntheſis*. When, for inſtance, by combining water with alcohol you form what is called brandy, or ſpirit of wine, you have certainly aright to conclude, that brandy or ſpirit of wine is compoſed of alcohol combined with water. The ſame reſult may be produced by the analytical method.

Mr. Lavoiſier has treated atmoſpherical air in this manner, and endeavoured to aſcertain it's nature by decompoſing it, and forming it anew; I ſhall therefore here recount ſome of his intereſting experiments. He took a retort containing about 36 inches; the neck was ſo bent as to allow it's being placed on a furnace while the neck was inſerted under the glaſs receiver which was placed in a trough of quickſilver. Four ounces of mercury were put into the retort, and the air was extracted from the receiver by means of a ſyphon, ſo as to raiſe the mercury therein to a certain height, which height was carefully marked by a ſlip of paper. The height of the barometer and thermometer being noted, a fire was lighted in the furnace, and kept up continually for 12 days, ſo as to keep the quickſilver always almoſt at the boiling point.

Nothing remarkable appeared during the firſt day: the mercury, though not boiling, was continually evaporating, and covered the interior ſurface of the veſſel with ſmall drops, at firſt very minute, which gradually augmenting to a ſufficient ſize, fell back into the maſs at the bottom of the veſſel.

On the ſecond day, ſmall red particles began to appear on the ſurface of the mercury, which during the four or five following days gradually increaſed in ſize and number, after which they ceaſed to increaſe in every reſpect. At the end of 12 days, as the calcination of the mercury did not increaſe, the

the fire was extinguiſhed, and the veſſels ſuffered to cool.

The volume of air, in the body and neck of the retort, and in the receiver, reduced to a medium of 78 inches of the barometer, and 54° of the thermometer, at the commencement of the experiment, was 50 cubical inches; but at the end of the experiment, the remaining air reduced to the ſame medium of preſſure and temperature, was only between 42 and 43 cubic inches; conſequently it had loſt about *five-ſixths* of it's volume. The red particles were afterwards collected, and found to amount to 45 grains.

The air which remained after the calcination of the mercury in this experiment, and which was reduced to five-ſixths of it's former bulk, was no longer fit either for reſpiration or combuſtion; animals introduced into it were ſuffocated in a few ſeconds; and when a taper was plunged therein, it was extinguiſhed, as if it had been immerged in water.

Mr. Lavoiſier then took the 45 grains of red matter formed during the experiment, and put them into a glaſs retort, with a proper apparatus for receiving ſuch liquid or aerial fluid as might be extracted. Having applied fire to the retort in a furnace, he obſerved that in proportion as the red matter was heated, the intenſity of it's colour augmented. When the retort was almoſt red-hot, the red matter began gradually to decreaſe in bulk, and in a few minutes after it diſappeared altogether; at the ſame time forty-one and half grains of running mercury were collected, and ſeven or eight cubical inches of an elaſtic fluid, much more capable of ſupporting both combuſtion and reſpiration than atmoſpheric air. A taper burned in it with a dazzling ſplendor; charcoal, inſtead of conſuming quietly, as it does in common air, burnt with a flame attended with a decrepitating noiſe,

and threw out ſuch a brilliant light, that the eye could hardly indure it.

If you reflect upon this experiment, you readily perceive, that the mercury, during it's calcination, abſorbs the pure and reſpirable part of the air; that the remaining part is a ſpecies of mephitis, incapable of ſupporting combuſtion or reſpiration; and conſequently *that atmoſpheric air is compoſed of two elaſtic fluids, of different and oppoſite qualities*. As a proof of this, if theſe two elaſtic fluids are re-combined, that is, the 42 cubical inches of mephitis, or phlogiſticated air, with the 8 cubical inches of vital air, you reproduce an air apparently ſimilar to that of the atmoſphere, and poſſeſſing nearly the ſame power of ſupporting combuſtion and reſpiration.

As during the calcination of mercury air is decompoſed, and the baſe of the reſpirable part fixed and combined with the mercury, it follows from what has been already eſtabliſhed in our Lectures, that fire and light muſt be diſengaged during the proceſs; but it is not ſenſible in this experiment for the following reaſons: As the calcination laſts ſeveral days, the fire and light that is diſengaged in ſo conſiderable a ſpace of time, becomes extremely ſmall for each particular moment of that time, ſo as not to be perceptible, and further is alſo confounded with that proceeding from the furnace.

It is, however, eaſy to render this diſengagement of fire and light evident to the ſenſes, by cauſing the decompoſition of the air to take place in a more rapid manner. For this purpoſe iron is well adapted, and we ſhall therefore relate to you Dr. Ingenhouſz's curious experiment, which we exhibited to you in one of our laſt Lectures. You remember that the inſtant the tinder came in contact with the vital air, the iron wire took

took fire, and burnt rapidly, throwing out brilliant ſparks. When every thing has been properly arranged and conducted, according to Mr. Lavoiſier's method, the whole wire is conſumed even to the laſt particle; the globules of iron will be found in that ſtate called *martial ethiops*. If the experiment be well made from 100 grains of iron, you will obtain 135 or 136 grains of ethiops, which is an augmentation of 35 per cent. Theſe experiments will be ſufficient to give you ſome idea of the nature of atmoſpheric air; you will find many more to the ſame purpoſe in the later chemical writers; ſhewing clearly, that the mixture of about 72 parts of phlogiſticated air, and 28 of vital air, form a fluid ſimilar to the maſs in which we live. Theſe two principles are ſo well mixed therein, each of them ſo neceſſary to the ſupport of the various functions of individuals which live and vegetate upon the globe, that they have not yet been found ſeparate and alone. The proportion of theſe gaſes is ſubject to variations, which depend on local cauſes that cannot poſſibly be aſcertained.

The characteriſtic properties of vital air are modified by thoſe of phlogiſticated air; and theſe modifications ſeem to be neceſſary, for if we were to reſpire vital air in it's purity, it would quickly conſume our life. Though it may be uſeful as a medicine, the candle of life would burn out too faſt, and the animal powers be too ſoon exhauſted in the pure air.

Mr. Lavoiſier, from the foregoing experiments, conſiders atmoſpherical air as a mere *mixture* of vital and phlogiſticated airs. For this he has no other reaſon than that by applying ſubſtances to it which have an affinity to vital air, the portion of this fluid that is in the atmoſpherical air is abſorbed, while the reſiduum is only phlogiſticated air.

 But

But this fact may only ſhew, that atmoſpherical air can be *decompounded*, and that it may be conſidered as a chemical *compound*, conſiſting of a given proportion of vital and phlogiſticated airs. There are indeed many reaſons to induce us to prefer this conſideration, that *atmoſpherical air is an homogeneous fluid*, or in other words, an uniform chemical compound, to that of it's being a mere mixture of two diſtinct fluids.*

Thus we find vital air and phlogiſton are capable of combining in a variety of proportions, and conſequently of aſſuming different forms: there is therefore no improbability in ſuppoſing atmoſpherical air, as it conſiſts of the ſame elements, to be alſo an uniform compound.

Further, atmoſpherical air is found by eudiometrical experiments to be very uniform in the proportion of it's conſtituent parts of pure and phlogiſticated airs. If it were a mere mixture, one ſhould expect to find a great diverſity therein; but being a compound of a given proportion in it's conſtituent parts, which proportion is undoubtedly the beſt poſſible for it's purpoſes of maintaining animal and vegetable ſubſtances, and other important uſes to which it is deſtined; it is kept very nearly of one uniform compoſition, or degree of purity, as it is called.

If the atmoſpherical fluid conſiſted of a mere mixture of theſe two airs floating together in the ſame ſpace as they are of different ſpecific gravities, they would ſeparate; the pure air remaining near the ſurface of the earth, and the phlogiſticated air aſcending. But from the comparative obſervations which have been made of the purity of the air in valleys and at the tops of lofty mountains, there is reaſon to believe, that no ſuch ſeparation takes place.

Of

* Keir's Chemical Dictionary, part 1, p. 125.

OF NITROUS AIR.

Nitrous air was firſt diſcovered by Dr. Hales, who produced it from the Walton pyrites, by means of the ſpirit of nitre: he alſo obſerved, that when joined to common air, an effervefcence enſued, with a turbid red colour of the mixture, and an abſorption of part of the common air. Dr. Prieſtley extending the experiment to other metallic ſubſtances obſerved, that the ſame kind of air was by the ſame acid readily procured from iron, copper, braſs, tin, ſilver, quickſilver, biſmuth, and nickil; and that though it conſtantly, when joined to common air, exhibited thoſe appearances mentioned by *Dr. Hales*, and more conſpicuouſly in proportion to the purity of the common air mixed with it (that is, it's fitneſs for reſpiration); yet it made no change with either fixed or inflammable air, or that air tainted by the breath of animals, or the corruption of their bodies. By means of this teſt he was enabled to judge of the kind, as well as of the degree of injury done to common air by candles burning in it; and to perceive a real difference in the air of his ſtudy, after a few perſons had been with him there. Nay, a phial of air having been ſent him from the neighbourhood of a large town, it appeared upon a comparative trial to be inferior in quality to that taken up near Leeds. It was upon ſuch a proſpect of obtaining a criterion for diſtinguiſhing good air from bad, that *Lord Bacon* almoſt in a rapture breaks out: " There are noble experiments that can make this diſcovery, for they ſerve for a natural divination of ſeaſons."—" They teach men to chooſe their dwellings for their better health." Later experiments have ſhewn, that this teſt is not ſo advantageous as was at firſt ſuppoſed.

Nitrous air is one of the conſtituent parts of the nitrous acid, or it is rather the ſame deprived in a great degree of it's acid. It is compoſed, therefore, of the ſame parts as the nitrous acid, that is, of mephitis, or phlogiſticated air, holding a ſmall quantity of vital air, and combined with fire. In this ſtate it is not ſoluble in water; but if it be furniſhed with vital air, it becomes acid, and very ſoluble in water.

You may eaſily be convinced, both analytically and ſynthetically, that the baſe of phlogiſticated air is the nitrous acid, holding vital air, but not ſaturated with it, for in that caſe it would become the nitrous acid.

1. By analyſis, you may decompoſe the nitrous acid, and reduce it to the ſtate of nitrous air, by making it act on any metal, as copper, which takes away the greater part of it's vital air. Expoſing this air afterwards to liver of ſulphur, it is deprived of the remainder of the vital air, and nothing remains but phlogiſticated air. 2. By ſyntheſis, Mr. Cavendiſh introduced into a tube of glaſs 7 parts of vital air, obtained without the uſe of nitrous acid, and 3 parts of phlogiſticated air, or eſtimating them by weight, 10 parts of phlogiſticated to 26 of vital air: and having cauſed the electric ſpark to paſs through this air, perceived that it's bulk was conſiderably diminiſhed, and ſucceeded in converting them into the *nitrous acid.*

From this experiment it may be preſumed, that the nitrous acid is a combination of 7 parts of vital, and 3 of phlogiſticated air; that theſe proportions conſtitute the common nitrous acid. When it is deprived of a portion of it's vital air, it paſſes to the ſtate of nitrous air; ſo that, as we ſaid before, nitrous air is a combination of phlogiſticated air, with a ſmall quantity of vital air.

air. Nitrous acid may alſo be produced by expoſing vital air, for a long time, to the exhalations of putrifying animal ſubſtances, together with a calcareous earth, or any other proper baſe to receive and combine therewith.

The nitrous acid may alſo be inſtantly produced by mixing nitrous with vital air.

The exiſtence of nitrous acid in the atmoſphere has long been a very popular opinion; it however reſted upon no deciſive fact, till Mr. Cavendiſh, by an important experiment, ſeems to have placed it among eſtabliſhed truths. He has ſhewn, that by paſſing the electric ſpark through common air included in a glaſs tube, the air was diminiſhed in quantity, and nitrous acid was produced.

Common air being ſuppoſed to be a mixture of vital and phlogiſticated airs, he repeated the experiment on a mixture of theſe fluids as above related, and found that when mixed in due proportion, they were wholly convertible into the nitrous acid, or nitrous acid and water.

Now as the nitrous acid may be obtained either from a mixture of common and nitrous air, or of common and phlogiſticated air, it ſeems evident, that nitrous and phlogiſticated airs muſt contain the ſame elements, but that one of them is modified by vital air.

Nitrous air may be diſengaged from the acid, by making this act on combuſtible matters, which combine more or leſs with it's vital air, whilſt the phlogiſton thereof holds a ſmall quantity of vital air, which together with fire forms nitrous air; conſequently it may be extracted from the nitrous acid, by means of iron, copper, braſs, tin, ſilver, mercury, biſmuth, and nickel; and even from aqua regia, by gold and antimony. The acid muſt be

cautiouſly

cautiously applied to iron, on account of the strong emission of the fumes.

It may be obtained from the nitrous acid by spirit of wine, ether, oils, resinous substances, gums, sugar, &c. The properties thereof are the same, from whatsoever substance it be extracted.

It is obtained in largest quantities from metals. There are some, however, from which nothing can be obtained but phlogisticated air, because they deprive the acid of all it's vital air.

I put some thin pieces of copper into this bottle, which I *fill* with nitrous acid that I have previously diluted with water; I then put in a ground stopple and bent tube into the neck of the bottle, and introduce the tube under one of the jars (that are filled with water) of my pneumatic apparatus: a fermentation you see takes place in the bottle, the metal is dissolved, and the nitrous air rises through the water, and settles at the upper part of the inverted jar.

Nitrous is very little, if any thing, heavier than atmospheric air. Pure nitrous air is not at all miscible with water, as you may easily experience by agitating them together in a glass tube under water. It is not acid; does not change the blue colour of vegetables, such as the tincture of turnsole; as you will see by my passing a little of the tincture in this tube with nitrous air, the colour is not changed.

It does not maintain combustion. I plunge this lighted taper into it, you see how soon it is extinguished; before the flame went out it became of a green colour. It is unfit for respiration, and speedily kills both animals and plants. It possesses the remarkable property of uniting with vital air, with which it forms nitrous acid; when mixed therewith, it forms a red cloud, which is imbibed by the water, and renders it acid.

Here

Here is a long glaſs tube, divided into equal meaſures; I ſhall firſt put two meaſures of atmoſpheric air therein, and one of nitrous air; you obſerve that it fumes immediately, and becomes hot; and as the combination which now takes place forms nitrous acid, which is very ſolvible in water, you will ſee the water riſe in proportion as it abſorbs the acid; ſo that of three meaſures which were in the tube at firſt, only one and a half will remain; if the air was good, the reſiduum is azotic air. The heat produced in this experiment ariſes from the fire which is ſet at liberty. If inſtead of atmoſpheric air you put into the tube two meaſures of vital air, and two of nitrous, the whole will be nearly abſorbed by the water. Dr. Prieſtley found by various experiments, that when nitrous air is mixed with any other elaſtic fluid, they undergo no change, if the latter be unfit to ſupport combuſtion or animal life; but if the contrary, the red cloud is formed, and the whole bulk of the mixture is diminiſhed, accordingly as the air is more or leſs pure.

This property of nitrous air to abſorb the reſpirative part of air, and form the nitrous acid, enables us to uſe it as a *teſt* to diſcover the ſalubrity or portion of vital air in the compoſition of the atmoſphere: upon this principle *Eudiometers* are conſtructed. This inſtrument, however, is as yet imperfect; it will indeed ſhew to a certain degree of accuracy the proportion of vital air, and the ſalubrity of the atmoſphere, as far as it may depend on a certain portion of this air; but gives no information relative to the other noxious airs, &c. which, when mixed in the atmoſphere, alter and render it unwholeſome. Beſides which, it is very difficult to obtain nitrous air of the ſame degree of purity; and there are alterations in the appearances

or

or effect that may arise from a difference of temperature.

Nitrous air may be decomposed by exposing it to liver of sulphur; the vital air unites with the sulphur, and forms vitriolic acid, and leaves the azotic air behind in a state of purity. It may also be decomposed by pyrophorus, which burns therein and absorbs the vital air.

Mr. Van Marum has shewn, that this gas may be decomposed by the electric spark, that 3 cubic inches thereof were thereby reduced to one inch and 3 quarters, and that the residue no longer possesses any properties of nitrous air. The vitriolic acid absorbs nitrous air, and assumes a purple colour; marine acid imbibes it, and becomes blue: it is also absorbed by ether, alkaline liquors, and spirit of wine.

If nitrous acid be exposed to nitrous air, the latter is absorbed in large quantities, and the colour of the acid changes, first at the surface, and gradually through the whole liquid; the succession of colours are first yellow, then deep orange, next green, and lastly blue: by this absorption the acid is rendered much more volatile.

Of

OF FIXED AIR.

This acid is generally found in an aëriform ſtate: of the various elaſtic fluids it is that which has been longeſt known; from it's apparent acid qualities it has been named *aerial acid*, and carbonic acid; from it's noxious qualities it is often termed *mephitic air*. Van Helmont called it *gas ſylveſtris*, becauſe it was produced in vaſt quantities during the combuſtion of charcoal. The term *fixed air* was given thereto, becauſe it ſo rapidly loſt it's elaſticity, and fixed itſelf in many ſubſtances, particularly thoſe of the calcareous kind: it's nature is, however, far from being aſcertained. Many chemiſts conſider it as ſimple, or at leaſt as having never yet been decompoſed. It is about twice as heavy as common air; hence it occupies the lower parts of thoſe cellars, mines, caves, &c. that contain materials proper for it's formation.

The French chemiſts conſider fixed air as a combination of carbonne, (matter or principle of charcoal,) and vital air. They think this to be evident for the following reaſons: Firſt, that the calces of mercury are reducible without addition when diſtilled, and afford only *vital air*; but if a ſmall quantity of charcoal be mixed with the calx, the product which comes over is only fixed air, and the weight of the charcoal is diminiſhed. Secondly, that if well made charcoal be ignited, and plunged into a veſſel of vital air, and the veſſel be inſtantly cloſed, the charcoal burns rapidly, and at laſt goes out; the product is fixed air, and a ſmall quantity of vital air, which may be changed into fixed air by the ſame operation. The French chemiſts, conſidering nothing to be

preſent

present but charcoal and vital air, conclude that fixed air is a combination of these two principles held together by fire!

This gas, or air, is often to be found occupying the lower parts of mines, caverns, tombs, necessaries, and such other subterraneous places as contain materials for producing it. It is called choke-damp by the miners. The grotto del cano, near Naples, has long been famous for a mephitic vapour, which floats within a foot of the surface. It is a cave in the side of a mountain, near the lake Agnano, into which if you thrust a dog, or any other animal that holds down it's head, it is immediately killed by inhaling the noxious vapour. It exists in a state of simple mixture in mineral waters; in these it possesses all it's acid qualities.

It is emitted in large quantities from bodies in a state of vinous fermentation, such as wine, beer, &c. On account of it's great weight, fixed air occupies the space or upper part of the vessels where the fermenting process is going on. A variety of entertaining experiments may be made in this stratum of elastic fluid.* Lighted paper, or a candle dipped into it, is immediately extinguished, and the smoke remaining in the fixed air renders it's surface visible, which by agitation may be thrown into waves, and has a very pleasing effect. If a dish of water be immersed in this air, and briskly agitated, it soon becomes impregnated, and obtains the lively taste of Pyrmont water. In consequence of it's weight, fixed air may be dipped out in a pitcher, or bottle, and conveyed, if well corked, to a great distance. The effects produced by pouring this invisible fluid from one vessel to another, have a very singular appearance.

* Priestley's Experiments and Observations on Air, vol. i. p. 44. Nicholson's First Principles of Chemistry, p. 178.

pearance. If a candle, or ſmall animal, be placed in a deep veſſel, the former is extinguiſhed, and the latter expires in a ſecond, after the fixed air is poured upon them; though the eye is incapable of perceiving any thing thus poured out, and producing theſe effects.

This air is alſo furniſhed in great abundance by the reſpiration of animals, where the vital air, which has parted with a great portion of it's fire for the ſupport of animal life, combines with a carbonnous ſubſtance, which is diſengaged from the blood in the lungs. You have already ſeen how unfit this fixed air is for reſpiration. Hiſtory informs us, that the two ſlaves, whom Tiberius cauſed to deſcend into the grotto del cano, were immediately ſtifled. Two criminals, cauſed to be ſhut in there by Peter Toledo, ſuffered the ſame fate. The abbe Nollet, who had the courage to reſpire the air, perceived a ſuffocating ſenſation, and a ſlight degree of acidity, which produced coughing and ſneezing. The unfortunate Pilatre de Rozier cauſed himſelf to be let down into the gaſeous atmoſphere of a back of beer in fermentation: he had ſcarce entered the mephitis before ſlight prickings obliged him to ſhut his eyes, a violent ſuffocation prevented him from reſpiring, he felt a giddineſs, accompanied by thoſe noiſes which characterize an apoplexy: when he was drawn up, his ſight remained dim for ſeveral minutes, his countenance was become purple, he neither heard nor ſpoke, but with great difficulty. Theſe ſymptoms, however, all diſappeared by degrees.

It is this air which produces the many unhappy accidents at the opening of cellars, in places where wine, cyder, or beer, are ſuffered to ferment. Birds plunged into this air ſuddenly periſh. When the waters of Boulidou, of Perols, are dry, ſuch birds

birds as attempt to quench their thirſt in the clefts, are enveloped in the fatal vapour, and die.

Frogs, by ſuſpending their reſpiration, live from forty to ſixty minutes, when plunged in an atmoſphere of fixed air. Inſects are rendered torpid if they remain a long time in this air, but recover their vivacity as ſoon as they are expoſed to the open air.

Fixed air is combined with a great number of ſubſtances. It forms about one third of the weight of lime-ſtone, marble, calcareous ſpar, and other natural ſpecimens of calcareous earth, from which it may be extracted by heat, or by any acid ſtronger than itſelf. Stronger acids expel more fixed air than thoſe that are weaker. I ſhall ſhew you how to extricate this air from ſome marble groſsly powdered, with which I ſhall fill about a fifth part of this bottle, (which is furniſhed with a ground ſtopple and bent tube,) and then pour on enough water to cover the chalk, and add this ſmall quantity of oil of vitriol, being about a fourth or fifth part of the water. I now paſs the extremity of the tube through the water into the pneumatic tub, ſo that it may remain under the neck of this receiver, which is filled with water; a fermentation immediately takes place, which is accompanied with heat, as you will feel by applying your hand to the outſide of the bottle; and the elaſtic fluid, which is fixed air, is copiouſly emitted from the mixture, which paſſing through the bent tube, and the water, aſcends to the top of the receiver; in proportion as it fills this, the water gradually deſcends, and is at laſt quite expelled. We may now remove our bent tube and bottle to another receiver, and thus proceed till we have obtained as much fixed air as it will furniſh. This air is abſorbed by water, but the abſorption is very ſlow unleſs the water is agitated, by which means you

multiply

multiply the points of contact. I ſhall put three meaſures of fixed air into this graduated tube, and then agitate it briſkly in the water of our pneumatic tub, allowing time for the abſorption to take place. I now elevate the tube, and you ſee by the riſe of the water therein, how much air it has abſorbed. Water in general, under the common preſſure of the atmoſphere, and at a low temperature, abſorbs ſomewhat more than it's bulk of fixed air. It abſorbs more when cold than when it is heated. If water, impregnated with this air, be placed on a briſk fire, the rapid eſcape of the aerial bubbles gives it the appearance of boiling water, when the heat is not greater than the hand will bear. Congelation ſeparates this air completely from water, but no degree of cold or preſſure has yet exhibited it in a ſtate of concentrated or denſe fluidity.

Water impregnated with this air, acquires a pleaſant acidulous taſte, and the properties of ſimple mineral waters; it is eſteemed a powerful antiſeptic, and poſſeſſes very valuable medicinal qualities. The natural acidulous mineral waters do not differ from theſe, excepting in holding other principles in ſolution, and they may be perfectly imitated when their analyſis is known. It is abſurd to think that art is incapable of imitating nature in the compoſition of mineral waters. The operation is purely mechanical, conſiſting of the ſolution of certain known principles in water; we can and ought therefore to perform it ſtill better, as we have the power of varying the doſe, and proportioning the ſtrength of any mineral water to the purpoſes to which it is intended to be applied.

TO IMPREGNATE WATER WITH FIXED AIR.

For impregnating fixed air with water, Dr. Nooth's machine is the moſt effectual and conve-

nient. It conſiſts of three glaſs veſſels, (*fig.* 5, *pl.* 6.) The lower veſſel C contains the efferveſcent materials; the middle veſſel B is open, both above and below; it's inferior neck is fitted by grinding into the neck H of the lower veſſel; in the former is a valve; this valve opens and ſuffers the air to paſs; but the water cannot return through the tubes, partly becauſe the orifice is capillary, and partly becauſe the flat piece covers the hole; the middle veſſel is furniſhed with a cock E, to draw off it's contents; the upper veſſel A is fitted, by grinding, into the upper neck of the middle veſſel; it's inferior part conſiſts of a tube, that paſſes almoſt as low as the center of the middle veſſel; it's upper orifice is cloſed by a ground ſtopper F. When this apparatus is to be uſed, the effervefcent materials are put into the lower veſſel, the middle veſſel is filled with pure water, and put in it's place, and the upper veſſel is nearly ſtopped, and likewiſe put in it's place; the conſequence is, that the fixed air, paſſing through the valve at H, aſcends into the upper part of the middle veſſel B, where, by it's elaſticity, it re-acts upon the water, and forces part up the tube into the veſſel A; part of the common air in this laſt being compreſſed, and the reſt eſcaping by the ſtopper, which is made of a conical figure, that it may be eaſily raiſed; as more fixed air is extricated, more water riſes, till at length the water in the middle veſſel falls below the lower orifice of the tube; fixed air then paſſes through the tube into the upper veſſel, and expels more of the common air by raiſing the ſtopper; in this ſituation, the water in both veſſels being in contact with a body of fixed air, after a certain time becomes ſtrongly impregnated with that fluid. This effect may be haſtened by taking offthe middle and upper veſſels together, and agitating them.

The

The water, thus impregnated, has acquired acid properties; for it will change the blue infuſion of turnſole red: nay, if a weak ſolution thereof be only expoſed to fixed air, it acquires a reddiſh tint.

This air, and the water impregnated therewith, precipitates lime from lime-water: to prove this to you, I ſhall mix a little of this lime-water with ſome fixed air; you ſee the water aſſumes a milky appearance, and the lime is precipitated. The ſame effect would take place if I was to pour upon the lime-water ſome water impregnated with fixed air.

Lime combined with this air, forms chalk which is not ſoluble in water, but is precipitated thereby; lime-water is therefore a teſt for to diſcover this air. It was Dr. Black who firſt ſhewed that the cauſticity, ſharpneſs, and ſolubility in water of calcareous earths, was owing to their being deprived of fixed air; and that when they were combined with a proper quantity thereof, they were mild; the doctor giving them the name of *mild* when they were combined with fixed air, and of cauſtic when deprived of it.

Lime-water is precipitated by the vapour emitted by animals in reſpiration.

Fixed air combines with alkalies. It neutralizes both fixed and volatile alkalies, not only deſtroys their acidity, but gives them manifeſtly an acid taſte, and enables them to form cryſtals of a neutral or acidulous ſalt.

Some writers aſſert, that this air reſiſts putrifaction, abſorbing the putrid effluvia emitted from bodies. It is, however, improper for vegetation. Dr. Prieſtley, having kept the roots of ſeveral plants in water impregnated with this acid, obſerved that they all periſhed; and in thoſe inſtances where

plants vegetate in water, or in air which contains this gas, the quantity of gas is very ſmall. Mr. Senebier has obſerved, that plants, ſuffered to grow in water ſlightly acidulated with this gas, emit a larger quantity of vital air. Mr. Chaptal ſays, that the fungi which are formed in ſubterraneous mines, are almoſt totally reſolved into fixed air; but if theſe vegetables be gradually expoſed to the action of light, the proportion of acid diminiſhes, while that of the coaly principle augments, and the vegetable becomes coloured.

By paſſing the electric ſpark through fixed air, confined by mercury, the volume of air is augmented about one twenty-fourth part, and of this three fifths will be abſorbed by a ſolution of cauſtic alkali, and the remainder is inflammable. Many attempts have been made to explain this fact, but they are too unſatisfactory for relation.

Fixed air is heavier than common air. According to Mr. Kirwan, fixed air is to common air as 45.69 to 68.74; according to Mr. Lavoiſier, as 48.81 to 69.50.

As a knowledge of the nature of this air is highly neceſſary, in accounting for a variety of phenomena, I ſhall lay before you a ſummary of it's properties, to impreſs more ſtrongly what I have already mentioned to you. 1. It has added one more to the number of acids. 2. When calcareous alkalies and magneſia, in their uſual ſtate, are mixed with acids, an effervеſcence takes place, and fixed air is diſengaged from them. 3. It has cauſed a diſtinction to be made of all alkaline matter into two ſtates; the ſtate of *purity* or *cauſticity*, and the *mild* ſtate, having the property of effervеſcence. Alkalies, both fixed and volatile, become more cauſtic and more powerful ſolvents, when deprived of their fixed air; they are then alſo incapable

pable of cryſtallization, and efferveſcing with acids. The calcareous earths which are inſoluble in water, when deprived of their fixed air, are ſoluble therein; thus lime-ſtone is not ſoluble in water, but lime, that is, lime-ſtone deprived of it's fixed air, is ſoluble in water. It has thus removed from chemiſtry the difficulties it was under in accounting for the differences between the mild and cauſtic ſtate of lime and alkalies, and their efferveſcence with acids in the one, but not in the other: by pointing out this effect, Dr. Black, of Edinburgh, has been of the utmoſt benefit to ſcience, and now reaps the reward ariſing from well-deſerved and univerſal fame. 4. It gives the firſt inſtance of an acid which prefers lime to fixed alkalies. 5. It has explained the nature of mephitic caverns. 6. It has rendered the analyſis of waters more perfect, particularly ſuch as are called gaſeous, acidulous, and ſpirituous; and we have ſucceeded in imitating of them. 7. It has thrown great light on the ſolution of iron in many waters, and on the means of procuring martial waters ſimilar to thoſe in nature. Laſtly, it has opened a new field to the reſearches of chemiſts and natural philoſophers. Indeed every object in nature affords occaſion for philoſophical experiment, and every experiment which is made, even with an expreſs view to any particular inveſtigation, incidentally ſuggeſts matter for new inquiry. There is not an animal or a vegetable ſubſtance that we feed on, nor a ſaline ſubſtance that we taſte, nor a beverage that we drink, nor the air we breathe, nor a metal that we handle, nor a ſtone we tread upon, but what may furniſh matter for an infinity of experiments. It is by experiments that natural philoſophers explore ſecondary cauſes, which are ſteps that ought to lead the mind of man from earth to heaven; for the

 more

more diſtinctly you apprehend the number and connection of the ſecondary cauſes operating in this little ſyſtem which is ſubmitted to your view, the more certainly you will perceive the neceſſity of their ultimately depending, like the links of Homer's chain, on a FIRST.*

* Watſon's Chemical Eſſays, vol. iv. p. 354.

LECTURE

LECTURE XI.

OF INFLAMMABLE AIR.

THIS air is found ready formed in marſhes, ditches, and over the ſurface of putrid waters, in burying-places, in houſes of office, and in ſituations where putrid animal and vegetable matters are accumulated; it may alſo be extracted from the waters of moſt rivers and lakes, eſpecially thoſe in which great quantities of fermenting and putrifying matters are thrown. Dr. Franklin ſays, that in warm countries, if the mud at the bottom of a pond be well ſtirred, and a lighted candle be brought immediately after near the ſurface of the water, a flame will inſtantly ſpread a conſiderable way over the water, affording a very curious ſpectacle in the night time. Mr. Cavallo aſſures us, that it may be plentifully procured from moſt of the ponds round London: to do this, fill a wide-mouthed bottle with the water of the pond, and keep it inverted therein, then with a ſtick ſtir the mud at the bottom of the pond, juſt under the inverted bottle, ſo as to let the bubbles of air which proceed therefrom enter into the bottle; this air is inflammable. When by thus ſtirring the mud in various places, and catching the air in the bottle, you have filled it, you muſt put a cork in the bottle, whilſt the mouth is under water, and you may then take it home to examine the contents at leiſure. There are many inſtances recorded, of a vapour iſſuing from the ſtomach of dead perſons, which took fire on the approach of a candle; and ſuch air is probably often generated in the inteſtines of living animals. It is found in mines in ſuch quantities as to produce the moſt dreadful

effects. Being lighter than common air, it always rises to the top of those places where it is generated, so that it cannot be confined except in some vaulted place. By itself it is very noxious, and will instantly put an end to animal life; but when mixed with atmospherical air, may be breathed in much greater quantity than fixed air; it's great inflammability in this state, however, renders it very dangerous to bring any lights in those places where it abounds; it does not inflame unless mixed with atmospherical or with vital air, for pure inflammable air extinguishes flame as effectually as fixed or phlogisticated air; the explosion is more violent, and the flame more brilliant, when it is mixed with vital than with atmospherical air.

Inflammable air may be obtained in great purity by decomposing water, which is always a constituent part thereof. The French writers term it *hydrogene*, that is, *generator of water*.

Inflammable air may always be obtained from water by subjecting water to the action of a substance with which vital air has a greater affinity than it has to inflammable air: by this means the inflammable air is set free. Red-hot iron is often employed for this purpose; the iron during this process is calcined, and is changed into a substance resembling the iron ore from the island of Elba; in this state of calx it is much less attractible by the magnet, and dissolves in acids without effervescence.

Charcoal, in a red heat, has the same power of decomposing water; in this process fixed air is formed and mixed with the inflammable gas, but is easily separated by means of water or alkalies, which absorb the fixed air, and leave the inflammable pure. Inflammable air may also be obtained by dissolving iron or zinc in weak oil of vitriol; these two metals decompose water but very slowly, and

and with great difficulty, when alone, but do it with great eaſe and rapidity when aſſiſted by the vitriolic acid.

I put ſome iron-filings into this bottle, which is ſimilar to that we uſed in making fixed air, and then cover them with oil of vitriol, which I have diluted with water; a fermentation enſues, accompanied with heat; having let the common air eſcape from the bottle, I ſhall now put in the ground ſtopple and bent tube, and paſs the end of the tube into this bottle filled with water ſtanding on the ſhelf of our pneumatic apparatus, and you will ſoon ſee it filled with a fluid, which, on examination, you will find to be inflammable air.

If you heat an iron tube, kept red-hot in the furnace, the bent end of the tube being introduced under one of the receivers of the pneumatic apparatus, and then let water paſs through the tube by ſingle drops, an aerial fluid will be diſengaged, which, on trial, you will find to be inflammable air. As this experiment has been made by Mr. Lavoiſier in the moſt deciſive manner, and as it is the foundation of a new theory in chemiſtry, I ſhall endeavour to give you an accurate idea of the method uſed by Mr. Lavoiſier and his aſſociates. A gun-barrel was taken, into which was introduced a quantity of thick iron wire flattened by hammering. The gun-barrel and the flattened iron were weighed with the moſt ſcrupulous exactneſs, after which the gun-barrel was covered with a lute, for the purpoſe of ſecuring it from the immediate contact of the fire. It was then placed in a furnace with ſuch a degree of inclination that water would run through it. To the higher extremity was adapted a funnel to contain water, which was ſuffered to eſcape drop by drop, by means of a cock: the funnel was cloſed, to prevent any of the water

water from evaporating. To the inferior extremity of this gun-barrel was luted a tubelated receiver, to receive the water which ſhould eſcape decompoſition. Laſtly, to the tube of the receiver was fitted another tube, to convey the inflammable air to the pneumatic apparatus.

As a further precaution, a vacuum was made in every part of the apparatus, in order that the inflammable air might not be mixed with common air. Laſtly, when all theſe preparations were completed, the gun-barrel was made red-hot, and the water introduced drop by drop; an enormous quantity of inflammable air was diſengaged during the courſe of the experiment; when it was finiſhed, the gun-barrel was cleared of it's lute, and being weighed, was found to have acquired a conſiderable augmentation of weight: *this augmentation of weight added to the inflammable air obtained, gave a total very exactly equal to that of the water which had diſappeared.* The flat pieces of iron that had been introduced into the gun-barrel, and likewiſe the interior part of the gun-barrel itſelf, were converted into a thick ſtratum of black calx of iron, or martial ethiops, cryſtallized like the iron ore of Elba. The chemical analyſis of this ſubſtance proved, that the iron was reduced exactly to the ſame ſtate as that which had been burned in vital air.

Meſſrs. Lavoiſier, &c. were deſirous of forming water again with the ſame inflammable gas which had been obtained. It was burned in a proper apparatus, with a quantity of vital air equal to that which had been retained by the gun-barrel, and the ſame quantity of water was *reproduced* with ſufficient exactneſs; it amounted to ſomewhat more than ſix ounces. This double experiment is conſidered, by Mr. Lavoiſier, as a clear proof of the

poſſibility

poſſibility of decompoſing and recompoſing water, and of it's reſolution into oxigene and hydrogene.

Inſtead, however, of aſſerting from hence that water is formed by the combination of the two gaſſes, it would be more philoſophical, as *nearer the fact itſelf*, to ſay, that the water obtained in this experiment ariſes from the mutual decompoſition of theſe two gaſſes, of which it probably forms the ponderable part.

Philoſophers are agreed in allowing that water is the ſenſible *ponderable* product of the foregoing experiment; and the queſtion between them is, whether this water is *formed* by the union of the *ponderable baſes* of theſe fluids, or whether theſe baſes are not water itſelf, and which is therefore not *produced*, only *liberated*, in this experiment. By aſſerting that it is formed, the French writers have turned a *fact* into an *hypotheſis*.

Nothing indeed could be more convenient for the *antiphlogiſtic* chemiſts, than their ideas of the compoſition of water; for as this fluid exiſts, more or leſs, in almoſt all bodies, and in almoſt every chemical operation, and as it is, according to their theory, ſuppoſed to contain an *inflammable* principle, nothing could be more eaſy to account for all the phenomena before imputed to *phlogiſton*, than by ſubſtituting for this *old inflammable* principle the *new inflammable principle* of water. The doctrine of the compoſition and decompoſition of water has accordingly been the univerſal *Edipus* that unlocks all the myſteries of chemiſtry; the *cauſa ſine qua non* of the French ſchool, * a ſchool in which hypotheſes are continually taken for granted as aſcertained truths, and in which opinions, that in a conjectural

* Keir's Dictionary of Chemiſtry, firſt part, Preface, p. 7. Dictionary, p. 207.

conjectural ſyſtem are proper objects of diſcuſſion, are admitted as facts and demonſtrated truths.

It has often been objected to the phlogiſtic theory, that phlogiſton was merely a being of hypotheſis, while the French ſchool boaſt that their theory, if it can be ſo called, is nothing but *an expoſition of facts*. You will find, on inveſtigation, that their theory is at leaſt as full of hypotheſis as that which they oppoſe. Thus their carbonne and hydrogene are not ſubſtances which have ever been exhibited to our ſenſes, or inferred by any certain induction.

Their carbonne is ſuppoſed to be the remaining part of charcoal after it has been diveſted of earth and fixed ſalts. It nevertheleſs is ſuppoſed to retain the peculiar properties of charcoal in forming fixed air when united with vital air. But what fact aſcertains the exiſtence of ſuch a being, or it's poſſibility of forming fixed air, when deprived of all it's earth and ſalts? Of their hydrogene we have already ſpoken.

The great quantity of inflammable air produced in warm climates, has made ſome conjecture that it may have a conſiderable ſhare in producing certain atmoſpherical meteors. The weak lightnings, without any exploſions in the atmoſphere, are by them conjectured to proceed from inflammable air fired by electric exploſions. M. Volta ſuppoſes, that the *ignes fatui* are occaſioned by the inflammable air, which proceeds from marſhy grounds; but theſe phenomena may be better accounted for by the action of the electric fluid alone.

This gas is more common than any other of the noxious airs, for there is hardly any inflammable ſubſtance from which it may not be extracted. The fluids, however, which go by the name of inflammable

flammable air, have often no other property in common but inflammability, and being lighter than common air. The ſmell, weight, power of burning, of preſerving their properties, and the phenomena attending their combuſtion, differ very much, ſome burning in an exploſive manner, others quietly with a lambent flame.

There is a diſtinction neceſſary to be made between an inflammable elaſtic fluid, and that which is made by combining an inflammable ſubſtance with common air. Thus, a drop of ether put into a quantity of common air mixes itſelf with it, and takes fire on the approach of flame like inflammable air; but if waſhed with water, the ether is immediately ſeparated from the air. Common air becomes alſo inflammable by being tranſmitted through ſeveral eſſential oils, and thus air contiguous to the plant, called fraxinella, becomes inflammable in calm hot weather, by the emiſſion of it's inflammable air. Inflammable air is often mixed with other ſubſtances, which it holds in diſſolution, and which conſtitute five varieties, viz. hepatic gas, phoſphoric gas, mephitized inflammable gas, cretaceous inflammable gas, carbonaceous inflammable gas.

OF PURE INFLAMMABLE AIR.

This air has a very diſagreeable ſmell, which it even retains when mixed with a large quantity of common air: you remember when I made ſome juſt now, it filled the whole room with it's offenſive ſmell, which is not even yet diſſipated.

It gives no ſigns of acidity, it does not precipitate lime from lime-water, nor change the colour of turnſole; when it is very pure, you may eaſily

easily preserve it in bottles that are well corked, and that though there should be water in the bottles, for it is not soluble in water.

Inflammable air is not proper for respiration. Birds successively placed in a vessel filled therewith died, without producing the smallest perceptible change in the gas itself. Mr. Chaptal found that frogs, in forty inches of inflammable air, died in the space of three hours and a half, while others lived fifty-five hours in vital and atmospheric air; when taken out they were still alive, the air was neither vitiated nor diminished. From a variety of experiments, he found that these animals have the faculty of stopping their respiration, when placed in any noxious gas, to such a degree, that they only inspire once or twice, and afterwards suspend every function on the part of the respiratory organ.

This gas does not appear to be changed by the human respiration, and M. Chaptal thence infers that it is not respirable; for if it were, it would suffer a change in the lungs, the object of respiration not being confined merely to the reception and emission of a fluid. It's functions are more noble, more interesting, and more intimately connected with the animal œconomy. We should consider them as an organ nourished by the air, digesting that part which is presented to it, retaining the beneficial, and rejecting the noxious part. Inflammable air may, indeed, be respired several successive times without danger to the individual, or without any change or alteration in itself; we may conclude from thence, that inflammable air is not poison; but we cannot infer from thence, that it is proper for respiration.

Inflammable air is not combustible alone, it does not inflame without the concurrence of vital air. I shall take this vessel, which is filled with inflammable

inflammable air, from our pneumatic apparatus, placing my thumb on the mouth thereof to prevent the air from efcaping; I fhall prefent the mouth to the flame of this candle, which immediately inflames the air at the furface, and the flame gradually defcends lower and lower to about the middle of the bottle; but it burns only while in contact with the air; for the moment I clofe the bottle the flame goes out. Here is another bottle filled with this air, I prefent a lighted taper thereto, and the furface is inflamed; I plunge it lower, and it is immediately extinguifhed. Even the moft inflammable bodies, fuch as phofphorus, do not burn in an atmofphere of inflammable air. It's inflammation is, however, more rapid in proportion to the furface expofed to the air.

Here is a fmall piftol, in which I fhall mix inflammable and common air, then ftop the mouth with a cork, and fire the air by a fpark from our electrical machine. You obferved how loud the noife of the explofion, and you fee with what force it has driven out the cork. It muft needs appear fingular to you to fee a piftol charged and exploded by the combuftion of an *invifible* fubftance.

The neck of this bladder is tied to a metal pipe, the bladder is filled with inflammable air; I fhall inflame the air by applying the flame of a candle to the extremity of the pipe, fqueezing at the fame time the bladder; thus a beautiful ftream of fire is formed in the air, which will laft as long as I force out the inflammable air. You muft be careful, in repeating this experiment, to keep continually preffing the bladder, to prevent the entrance of atmofpheric air, by which that within the bladder would explode with violence, and burft the bladder to pieces.

On this principle artificial *fireworks* have been conftructed, without fmoke and without

noife,

noiſe, by filling the bladder with this air, and forcing the air through tubes bent in various directions, furniſhed with ſtop-cocks, and pierced with a great number of holes; the air is forced through theſe holes by preſſing the bladders, and is inflamed by a taper, and continues to burn as long as you preſs the bladders, or till you turn the ſtop-cocks. Mr. Dillier exhibited ſome very beautiful fireworks of this kind, at London, of different figures and colours. The colour varying with the mixture, one third of the air of the lungs mixed with the inflammable air of pit-coal, gives a blue coloured flame; inflammable mixed with nitrous air, affords a green colour; the vapour of ether affords a white flame.

Inflammable air is lighter than common air; a cubic foot of atmoſpheric air weighs 720 grains, a cubic foot of inflammable air 72 grains. The barometer being at 23.3, and the thermometer at 60, the weight of this air, to that of common air, was found as 84 to 1000; conſequently it is about twelve times as light. It's ſpecific gravity varies very much, becauſe it is difficult to obtain it conſtantly of the ſame degree of purity. The theory of balloons, or aeroſtatic machines, is founded on the levity of inflammable air. It is ſufficient that the weight of the balloon itſelf, and the air it incloſes, ſhould be lighter than an equal bulk of common air, and it muſt riſe till it's weight is in equilibrio with an equal volume of the ſurrounding medium.

OF HEPATIC AIR.

Inflammable air poſſeſſes the property of diſſolving ſulphur, in which caſe it contracts a very fœtid ſmell, and forms hepatic air.

Mr. Gengembre put ſulphur into inverted veſſels

veſſels filled with inflammable air, and diſſolved it by means of a burning-glaſs, and found it poſſeſſed all the diſtinctive characters of hepatic air. It is generally obtained from liver of ſulphur, or ſolid hepars, decompoſed by means of acids in the pneumatic apparatus; it is extricated in vaſt quantities, by pouring marine acid on hepar ſulphuris. If inflammable air be paſſed through melted ſulphur, it is converted into hepatic air. The formation of this gas is generally effected by a decompoſition of water. In fact, livers of ſulphur do not emit any diſagreeable ſmell while they are dry; but the moment they are moiſtened, an abominable ſmell is perceived, and vitriolated tartar begins to be formed. Theſe phenomena ſhew that the water is decompoſed; that the inflammable air unites to the ſulphur, and together with fire volatilizes it, while the vital air unites with the alkali, and forms a more fixed product.

It is not fit for reſpiration, and turns the ſyrup of violets green. If pure air be mixed with it, the oxigene thereof combines with the hydrogene, and precipitates the ſulphur; for the ſame reaſon it is decompoſed by the ſmoking the ſulphureous acid.

It takes fire by the contact of inflamed bodies, or by the electric ſpark, and burns with a reddiſh blue flame, depoſiting ſulphur at the ſame time on the ſides of the veſſel. It detonates when ſet on fire in vital air; it is very ſoluble in water, which it converts into a ſtate perfectly reſembling that of the ſulphureous mineral ſprings; it is probable, therefore, that it is this gas which impregnates ſulphureous water; it's great attraction for ſome metals, and their calces, makes it the baſes of ſome ſympathetic inks. It's ſpecific gravity, compared to that of atmoſpheric air, is as 1106 to 1000.

 Phos-

PHOSPHORIC AIR.

This is inflammable air, in which phoſphorus has been diſſolved. It was obtained by Mr. Gengembre, by boiling a ſolution of cauſtic vegetable alkali, with half it's weight of phoſphorus, and receiving the elaſtic fluid, which was diſengaged under glaſs veſſels filled with mercury. It cannot be collected in water, being very ſoluble therein. It has a very fœtid ſmell, and is unfit for reſpiration.

It takes fire *ſpontaneouſly* by the contact of air, accompanied with an exploſion, which may prove dangerous, if you preſent too large a quantity of air at once. When vital air is mixed with this gas, it burns with great rapidity, producing a great degree of heat, which dilates the receivers ſo much, that they are ſometimes ſhattered to pieces. As this phoſphorus takes fire on contact with the air, it communicates it's combuſtion to the inflammable air.

It is probably to a diſengagement of a gas of this kind, that we may attribute the ignes fatui, which play about burying grounds, and in general all places where animals are buried and putrify. It is to a ſimilar gas that we may refer the inflammable air, which conſtantly burns in certain places, and upon the ſurface of certain cold ſprings.

INFLAMMABLE CARBONIC GAS.

It is now ſuppoſed, that charcoal, though fixed in cloſed veſſels, and in our ordinary fires, contains a carbonaceous principle, denominated by the French writers carbonne, which may be reduced into vapours by a great degree of heat; and that it is ſoluble by aeriform fluids, more particu-

larly

larly by inflammable air, which often combines with it when aſſuming the aerial ſtate.

This air is diſengaged, when caſt iron or ſteel is diſſolved in ſpirit of vitriol. Charcoal may be diſſolved in this gas by a burning-glaſs, when the gas is in the mercurial part of the pneumatic apparatus; though this modifies it's effects, and alters the reſults of it's combinations; it burns with a blue flame, throwing out white or reddiſh ſparkles.

Mr. Berthollet ſuſpects, that a mixed gas formed by a ſolution of charcoal in mephitis, is the colouring matter of the *Pruſſian blue.*

CRETACEOUS INFLAMMABLE AIR.

This is the mixture of inflammable and fixed air, but without combination. It is obtained by diſtillation from many vegetable matters, from tartar, from all the tartarous ſalts, from hard woods, or charcoal, which is burned, by the aſſiſtance of water, from pitcoal, &c. It burns with difficulty; but though three-fourths of it's bulk be formed of fixed air, it ſtill remains combuſtible.

The inflammable may be ſeparated from the fixed air, by means of lime-water, or cauſtic alkali, with which the fixed air combines.

INFLAMMABLE AIR FROM MARSHES.

This is inflammable air mixed with phlogiſticated air. It is produced by the putrifaction of many vegetables, and of almoſt all animal ſubſtances. It is diſengaged from ſtanding waters, and all places where animals putrify in water. It accompanies, precedes, or follows the formation of the vola-

tile alkali, which takes place in putrifaction. It is a ſimple mixture without combination. It burns with a blue flame; it detonates, but with difficulty, in vital air. After detonation, in Mr. Volta's Eudiometer, ſome drops of water are found, and a reſidue of phlogiſticated air, more or leſs pure.

MURIATIC ACID GAS.

This air is not found exiſting, or ready formed in nature; but is an artificial production; it is obtained by heating ſpirit of ſalt, or liquid muriatic acid in a retort, whoſe neck is plunged beneath a veſſel filled with mercury. It may be produced in the ſame apparatus by heating a mixture of common ſalt and oil of vitriol. It cannot be collected in water, as it is quickly abſorbed thereby. It ſeems to be nothing more than the muriatic acid, deprived of part of it's water, and combined with ſo much fire, as will make it aſſume an elaſtic aeriform ſtate.

This air has a ſtrong penetrating ſmell, being the muriatic acid; it gives the ſame ſigns of acidity, and reddens blue vegetable colours; but does not deſtroy them like oxygenated muriatic acid. It abſorbs the vapours of water, which float in the air, and forms with them a white fume. It melts ice with great rapidity, on account of the great heat ſeparated from it on it's combination with water. It is abſorbed by charcoal and by ſponge, unites with all alkaline baſes, and forms muriatic ſalts. It diſſolves camphor. It is deſtructive of animal life. On dipping a candle into this air, the flame is extinguiſhed; but the moment before it goes out, and when it is firſt lighted again, it burns with a green or light blue flame. This gas is conſiderably

ſiderably heavier than common air, in the proportion of 5 to 3; a cubic inch weighs 0.654 grains: it does not act on metals.

Oxygenated, or dephlogiſticated muriatic gas is obtained with great facility during the mutual action of the native calx of manganeſe, and the muriatic acid.

It is conſidered by ſome as the marine acid deprived of phlogiſton; by others, as the marine acid combined with vital air.

It is of a yellowiſh green colour, of a ſtrong penetrating ſmell, and quickly deſtroys animal life.

It decompoſes volatile alkali, which may therefore be uſed as a preſervative againſt it's noxious effects, ſeparating the phlogiſticated air from the alkali in proportion as it's own vital air unites with the inflammable gas of the volatile alkali, with which it forms water. It thickens fat oils, calcines metals, and is abſorbed by water, to which it communicates all theſe properties. It will ſupport flame, but is fatal to animal life.

It is gradually decompoſed by the contact of light, and reduced to the ſtate of pure muriatic acid.

It is one of the moſt ſingular diſcoveries of modern chemiſtry.

It is abſorbed almoſt as readily as fixed air by water, but may be eaſily expelled again by heat, and received in veſſels containing mercury; but the air thus expelled, does not readily again incorporate with water: the electric ſpark renders it wholly immiſcible with water.

It *deſtroys all vegetable colours*. It does not, like acids, redden litmus and ſyrup of violets, but renders them white, and has the ſame effect on dyes. It bleaches yellow wax. On account of this whiten-

ing quality, it has been applied ſucceſsfully to *bleaching of linen*, in caſes where expedition is preferred to œconomy.

It does not, however, affect all vegetable colours in the ſame manner and degree. The colouring matter of brazil wood, and ſome green parts of plants, retain a yellow tint. The leaves of *ever-greens* long reſiſt it's action, and at laſt only acquire the yellow colour which they receive by a long expoſure to the air.

Inflammable ſubſtances reduce it to the ſtate of common muriatic acid.

SULPHUREOUS ACID AIR, OR VITRIOLIC ACID AIR.

This is the product of art. It is formed whenever a combuſtible body takes away a part of the vital air, which is united to ſulphur in the vitriolic acid. It is alſo formed when ſulphur, burning ſlowly, abſorbs but a ſmall quantity of vital air from atmoſpheric air.

To procure vitriolic acid air, ſtrong concentrated vitriolic acid is to be put into the uſual bottle with any proper ſubſtance; olive oil anſwers the purpoſe very well; there ſhould be about three or four times as much oil of vitriol as ſweet oil, and both together ſhould fill about one third or half the bottle. A gentle degree of heat is neceſſary to make theſe materials yield the elaſtic fluid.

It is very ſoluble in water, and deſtroys many vegetable colours, ſo that it's oxigene muſt be either totally or nearly diſengaged.

When united with alkaline baſes, it forms neutral ſalts, different both in figure and taſte from thoſe which are formed by the vitriolic acid, and particularly in this, that they may be decom-

poſed

poſed by more feeble acids. It melts ice with great rapidity.

It is heavier than common air, extinguiſhes combuſtion, and deſtroys animal life.

If this air be mixed with alkaline air, it forms a beautiful white cloud, which becomes condenſed, and is found to be vitriolic ammoniac: at the ſame time a yellow ſubſtance is ſeparated, which ſeems to be ſulphur. Water impregnated with this air, may be frozen without parting with the air, and if ſuch water be incloſed in a glaſs hermetically ſealed, and be then expoſed to heat for ſeveral days, it depoſits ſulphur.

It is heavieſt of all aerial fluids, except fluor acid air, being to common air as 2265 to 1000.

FLUOR ACID GAS.

If pure fluor, or ſpar, that ſpecies of ſubſtance which is called the Derbyſhire ſpar, and of which you have ſeen ſo many ornaments for chimnies made, be placed in a retort of lead, with a receiver of the ſame metal adapted, and vitriolic acid be then poured upon it, the acid of ſpar will be diſengaged in an aerial form, by the application of a very gentle heat. The fluor acid air is at firſt produced without heat; but in a ſhort time it will be neceſſary to apply the flame of a candle to the bottle, by which means a conſiderable quantity of this elaſtic fluid is obtained. This air readily combines with water, and therefore when experiments are to be made with it in an elaſtic ſtate, it muſt be received over mercury.

The diſtinguiſhing property of this acid is that of diſſolving ſiliceous earth. The firſt experiments made with it were in glaſs veſſels; and it was obſerved, that an earthy matter was depoſited at the inſtant the air came in contact with the water in the recipient; this was found upon exa-

mination to be ſiliceous earth. It has been found by ſubſequent experiments, that this acid corrodes glaſs. It has therefore been uſed to make etchings upon glaſs in the ſame manner as the nitrous acid has been long applied to copper.

ALKALINE ACID GAS.

This air was produced at firſt by Dr. Prieſtley from common ſpirit of ſal ammoniac, with quick-lime. This air, when pure, is inſtantly fatal to animal life, and extinguiſhes flame: juſt however before the flame of a candle goes out, it is enlarged by the addition of another flame, of a pale yellow colour. The electric ſpark taken therein, appears of a red colour, and by degrees changes it into inflammable air.

On confining ſome water, impregnated with alkaline air, to a ſtrong heat for ſome days, a white ſediment, or cruſt, was formed on the ſurface.

Copper, which is ſo eaſily corroded by the common volatile alkalies, is not corroded at all by this air.

Bits of linen, charcoal, and ſponge, admitted into it, abſorb it, and acquire a very pungent ſmell. It diſſolves ice almoſt as readily as an hot fire.

The ſpecific gravity of this air is to that of common air, as 600 to 1000.

Dr. Prieſtley procured it by mixing one part of pounded ſal ammoniac with three parts of ſlack lime. When changed into inflammable air, it has been conjectured, that the change is occaſioned by heat alone, without the concurrence of light.

ABSTRACT

Abstract of a Dissertation on Phlogiston, by Mr. Wieglib, a German Chemist.

In oppoſition to the French theory Mr. Wieglib aſſerts,

1. That there exiſts in combuſtible bodies, and in many which are not ſo, a certain inflammable principle, which is ſeparated when they are in combuſtion; and that metals, by means of fire, are reduced to a calx.

2. This principle may be collected during the combuſtion of theſe bodies, and is found in a ſtate nearly ſimple in the form of gas.

3. That it is much lighter than any known matter.

4. That all bodies that are combined with this principle, loſe part of their ſpecific gravity, and that in proportion to the quantity of phlogiſton combined with them; but increaſe in weight by being deprived thereof.

5. This principle has a great affinity with vital air; their mixture is ſuſceptible of a very great condenſation, and changes into phlogiſticated air.

6. That combined with water and fire (the matter of fire), it forms inflammable air.

7. United with phoſphoric acid, it forms phoſphorus, and with the vitriolic acid ſulphur.

8. Charcoal is compoſed of this inflammable principle, and fixed air, with which ſaline and earthy particles are mixed.

9. We are ignorant of the conſtituent parts of vital air; perhaps it is compoſed of the principle of the pureſt water, and of the matter of pure fire.

10. We are equally ignorant of the conſtituent parts of fixed air; we can only exhibit it as a compound.

1. Of

1. *Of the existence of an inflammable principle.*

It is impossible to deny the existence of an inflammable principle in many bodies, unless the mind be led aside by the force of prejudice. The most ancient chemists were sensible thereof; *Geber* describes it under the name of *materiam fugitivam et inflammabilem, aut sulphureitatem adurentem*, evaporating from metals during calcination. The chemists of the middle age acknowledge it under the name of sulphur: *Becker* and *Stahl* rejected this denomination, and made use of the terms *inflammable principle* or *phlogiston*; they did not adopt it on mere hear-say; their own experience taught them, that by friction alone you might disengage from several metals, chiefly copper, lead, tin, and iron, a certain odour which became more sensible when the metals were melted, or during calcination, but which is still stronger when they are dissolved in acids.

The odour which escaped during these operations intimated the presence of this principle; and this supposition obtained more probability on examining the metallic calces, or the precipitates obtained by dissolutions, which are found to be deprived of the brilliancy peculiar to the metals, as well as of the above-mentioned odour. The absence of these properties naturally conducted them to this conclusion, that during the calcination or dissolution of the bodies, a certain principle escaped, which was the origin of the smell, and which communicated to metals their brilliancy and ductility. The heat and light diffused by a lighted candle, or coals in combustion, properties possessed by many other bodies, as oil, grease, tallow, pitch, wax, sulphur, phos-

 phorus,

phorus, wood, ſtraw, &c. conduct us to the ſame idea, i. e. that there exiſts in bodies an inflammable principle, on which their combuſtible properties depend.

But the truth of what is here only deduced from phenomena, is evidently proved by the reduction of metallic calces to perfect metals, by reſtoring to theſe calces, the *inflammable principle* that they had loſt by calcination.

The modern chemiſts have ſhewn us how to ſeparate this principle from different bodies, under the form of inflammable air; with this difference, however, that in the inflammable air there is alſo water combined with fire.

The preſence of this ſubſtance in inflammable air is proved by the properties and effects it produces, which are the ſame as thoſe by which inflammable air is diſtinguiſhed. Dr. Prieſtley obtained inflammable air by expoſing zinc and iron to a violent fire; the ſame reſult is found from the ſolution of theſe metals in the vitriolic and muriatic acid, and by expoſing to the focus of a burning-glaſs pure ſteel filings, contained in a veſſel filled with mercury.

It is impoſſible in theſe experiments to miſtake the inflammable matter in the form of inflammable air. A phenomenon obſerved by Dr. Prieſtley ſhould be noticed here: a kind of exploſion he obſerved, while the iron filings were heating, and which cauſed a portion of the filings to leap about. From this experiment we may conclude, that an aeriform ſubſtance is diſengaged from fire by heat, proving at the ſame time how ſmall a foundation there is for that theory, which conſiders the metals as ſimple ſubſtances. After what has been ſaid, there is little neceſſity for proving that charcoal contains phlogiſton. If the calcination of metals depends on a privation of this inflammable principle, their reduction or return

to

to their former ſtate, ſhould naturally take place when this principle is reſtored. But this reduction does not take place, unleſs the metallic calces are expoſed to the action of charcoal, or ſome other inflammable ſubſtance. Theſe ſubſtances muſt neceſſarily therefore contain the principle that co-operates to the reduction of metals. Beſides, we may further appeal to the inflammable nature of charcoal, which is ſo well known to every one. The nature of charcoal, it's exiſtence as an original ſimple principle, forms an eſſential link in the French chemiſtry, without which it cannot be ſupported. Though enough might be deduced againſt this notion, from what has been here ſaid; I ſhall take occaſion to notice it again in the courſe of this diſſertation.

2. *Separation of the inflammable principle.*

Though every one acknowledges, that inflammable air may be ſeparated from all inflammable ſubſtances, ſtill it is eſſential to prove, that air, known by the name of inflammable air, poſſeſſes the ſame properties that are attributed to the inflammable principle of certain bodies. Now every one knows, that nitre explodes only with inflammable ſubſtances, that is, that contain phlogiſton: this has been fully proved by Mr. Achard and others.

Mr. Achard conveyed ſome inflammable air obtained from a mixture of iron, and the vitriolic acid, into melted nitre, and a very conſiderable exploſion took place; and excepting a ſmall portion of alkali, all the remaining nitre was decompoſed. Meſſrs. Macquer and Montigny have alſo obſerved, that metallic calces might be revivified as well by inflammable air, as by powdered charcoal. Mr. Pelletier, in paſſing inflammable air through ſome arſenical acid diſſolved in two parts of

of water, obtained thereby an acid in a metallic form, which ſeparated itſelf from this liquor. All chemiſts know, that copper diſſolved in the vitriolic or muriatic, but principally in the nitrous acid, is found abſolutely in a ſtate of *calx*. It is alſo known, that while the vitriolic or muriatic acids attack the iron, inflammable air is diſengaged; but if the nitrous acid is uſed, nitrous air alone is produced. By expoſing, to either of the three diſſolutions of copper, a piece of poliſhed iron, the copper is immediately ſeparated therefrom, and recovers it's metallic brilliancy: during this experiment, no inflammable nor nitrous air is diſengaged, although the acids have certainly attacked the metal. It may be aſked, what is become of the inflammable principle of theſe airs. We anſwer, that it is united to the calx of the copper; for by what other means could the copper have re-acquired the inflammable principle it had loſt, but from the inflammable principle of the iron, which abandons the laſt metal to attach itſelf to the copper.

3. *Negative weight of the inflammable principle.*

The imponderability of this principle may be conſidered as a kind of axiom, for no one has been hitherto able to ſhew that it has any weight.

4. *The inflammable principle diminiſhes the gravity of bodies; for as ſoon as they are deprived thereof, they recover their original weight.*

M. Weiglib conſiders this as ſufficiently known to thoſe who are inſtructed in modern philoſophy; and in the courſe of theſe Lectures you will find this poſition illuſtrated by various arguments.

5. *Of the intimate combination of the inflammable principle with vital air, and the developement of phlogiſticated air.*

Though we conſider the exiſtence of an inflammable principle peculiar to combuſtible bodies, yet

yet we allow combuſtion cannot take place unleſs they are ſurrounded with either vital or atmoſpherical air: indeed the laſt ſeems only to acquire this faculty in proportion as it contains vital air, ſo that this may be conſidered as that alone in which combuſtion can be produced. There is a natural proportion eſtabliſhed between the quantity of the combuſtible body, and that of the air in which the combuſtion is made; for experiment ſhews, that the combuſtion never goes beyond a certain point, and that this point is more retarded in vital air than in any other. In all combuſtion volatile particles eſcape, in metals it is the inflammable principle alone which is diſengaged, in other bodies a variety of matters eſcape with this principle. Experiment ſhews, that combuſtion ceaſes in phlogiſticated or inflammable air; we may, therefore, ſuppoſe that theſe airs cannot abſorb the particles which eſcape from bodies in combuſtion, becauſe they are already ſufficiently loaded therewith. What we have here mentioned takes place more particularly in the ſimple calcination of metals; for as theſe contain no other principle that can be volatilized, they loſe nothing but their inflammable principle.

When metals are calcined, a phenomenon is obſerved, which is as it were the hinge or center of the new French chemiſtry, and about which all the doctrines thereof turn. When metals are calcined, or when combuſtion is performed, in cloſe veſſels filled with air, a conſiderable vacuum is formed in the veſſel, and the remaining air weighs leſs than the air that was before contained in the veſſel: on the other hand, the body which has been burnt, or the metal which has been calcined, will have acquired weight, and this increaſe of weight will be nearly in proportion to the loſs of weight in the air. Mr. Lavoiſier concludes, as we have obſerved before,

before, that the loſt air is abſorbed by the calx of the calcined metal.

Mr. Wieglib thinks Mr. Lavoiſier has forgotten that a condenſation of the air may have alſo taken place; and it is to this condenſation Mr. W. attributes the change in the air, ſupporting his opinion on an experiment of Dr. Prieſtley's, who found that by taking electric ſparks for a conſiderable time through a quantity of atmoſpheric air, that quantity was diminiſhed near one-fourth in bulk. Mr. De la Metherie has alſo proved by his experiments, that pure vital air may be diminiſhed by the electric ſpark, and changed into phlogiſticated air. Now if theſe experiments prove that vital air, when pure, or when mixed with atmoſpherical air, may be diminiſhed by electricity, it is evident that in the caſe, of which we are now ſpeaking, the ſame thing ſhould take place, unleſs it can be proved that a portion of this air has been abſorbed; but experiment proves, that this very ſenſible diminution of the maſs of air is owing to a real condenſation; for on introducing phlogiſticated vapour into the pureſt vital air, till it is completely ſaturated, there always remains behind a ſmall portion of phlogiſticated air. This is proved as well by the experiments of Mr. Lavoiſier as of other chemiſts, although they have conſidered this reſiduum of phlogiſticated air, according to their peculiar prejudices, as being anteriorly contained in vital air. Mr. Wieglib poured into a phial, containing 9 ounces of pure vital air obtained from manganeſe; he poured, I ſay, therein 4 ounces of a concentrated diſſolution of liver of ſulphur; the vital air then occupied a ſpace of 5 ounces; fifteen days afterwards the phial was opened under water, and the water on entering filled the whole phial, except a ſmall ſpace of about three grains and a half in capacity. Now if the vital air had been abſorbed,

abſorbed, there ſhould have been a perfect vacuum; but this was not the caſe, the ſmall reſiduum was phlogiſticated air. This experiment was repeated, but always attended with the ſame ſucceſs.

6. *Of inflammable air produced by the combination of water with the inflammable principle.*

Mr. Lavoiſier, and the friends of the French ſyſtem, think that ſome ſolid matter is neceſſary for the formation of inflammable air, that this matter acquires it's elaſticity by fire, and is one of the conſtituent or component parts of water. Mr. Wieglib conſiders fire as one of the conſtituent parts of this air, founding his opinion on Mr. Lavoiſier's own experiments.

By letting a copper tube 5 or 6 feet long, filled either with iron wire bent ſpirally, or elſe with charcoal, paſs through a violent charcoal fire, introducing at the ſame time the point of a ſmall glaſs alembic, which was filled with water, into the upper part of the tube, ſo that the vapour of the water paſſed through the tube, the lower end of which was immerſed in a phial filled with water, inflammable air was produced. If charcoal be employed, a good deal of fixed air is obtained at the ſame time, the iron contained in the tube is calcined, or if charcoal is uſed, it is changed into aſhes.

Mr. Wieglib thus explains the above-mentioned phenomenon; the water in paſſing through the tube combines with the fire, and is changed into vapour, which combining alſo with the inflammable principle of the iron, is thereby changed into inflammable air. Other experiments may be adduced to prove the ſame point.

7. *The combination of the inflammable principle with phoſphoric acid produces phoſphorus, with the vitriolic ſulphur.*

Whatever notions we now poſſeſs of the compoſition

poſition of natural or artificial bodies, we are indebted for them to an analyſis; phoſphorus and ſulphur were known before their conſtituent parts were diſcovered. The obſervation that phoſphorus ſhines when expoſed to the air, naturally led to the idea, that this luminous body contained an inflammable matter, which diffuſed itſelf in the air in the form of a luminous vapour. By purſuing this idea further, Homberg and Margraf found that this inflammable matter contained alſo an acid of a particular kind. From a knowledge of theſe two principles, later chemiſts have been able to form phoſphorus, by combining this particular acid with the inflammable principle.

It was the ſame with ſulphur, whoſe conſtituent principles were placed in the cleareſt point of view by the juſtly celebrated Stahl.

8. *That charcoal is compoſed of the inflammable principle and fixed air.*

Mr. Wieglib, before he explains his own propoſition, gives an account of Mr. Lavoiſier's notions concerning the peculiar principle of charcoal, carbonne, and the inflammable principle it contains.

Mr. Lavoiſier conſiders common charcoal as compoſed of carbonne, inflammable air, earth, and ſalt. In expoſing charcoal to a great fire in cloſe veſſels, Mr. L. obtained a ſmall quantity of inflammable air; but as theſe coals expoſed for a longer time to the ſame degree of fire, exhibited no change of aſpect, he conceived that by this operation he had ſeparated all the inflammable air. From this experiment Mr. L. conſiders the reſiduum as carbonne, a ſubſtance abſolutely ſimple, without proving the ſimplicity thereof.

Mr. Wieglib ſhews, that charcoal is a compound, conſiſting,

1. Of the inflammable principle.

2. Of fixed air.
3. Of terrestrial } particles.
4. Of saline }

The two last are contained in the ashes, and are only accessory, depending on the vegetables of which it is made, so that sometimes none of these particles are to be found.

Mr. Lavoisier's theory consists in considering his *carbonne* as a simple substance; and supposing in all the experiments (where there is a decomposition of charcoal) that the fixed air emaning therefrom, is a new compound. This error he has been led into, from not observing that charcoal is not decomposed when acted upon in close vessels; for in this case there is a diminution of the mass of air, and the residuum is fixed air. Mr. W. shews, that the air is always diminished when the inflammable principle combines with vital air; but as this, when it quits the charcoal, escapes into the air, the fixed air, disengaged by the same operation, naturally follows.

Fixed air has often misled the most able chemists, when they have endeavoured to prove it's existence; but on quitting the idea of it's artificial composition, which is far from being proved, we may always obtain every necessary knowledge. *Scheele*, whose abilities are universally acknowledged, is one who was thus misled, and we find him sometimes thinking he had formed this aerial acid (fixed air), sometimes that he had simply separated it. *Scheele* obtained fixed and inflammable air by exposing powdered charcoal to fire. By exposing also to a naked fire fixed caustic alkali mixed and ground with charcoal, in a glass alembic, using the pneumatic apparatus, you obtain a great quantity of inflammable air; the residuum has lost it's caustic nature, and will effervesce with acids, and is consequently loaded with fixed air. In this experiment

experiment the inflammable principle is ſeparated under the form of inflammable air, while the fixed air is combined with the fixed alkali.

By expoſing to an open fire a mixture of litharge and powdered charcoal, contained in a glaſs alembic ſolidly luted, we obtain, by means of the pneumatic apparatus, fixed air, and the litharge remaining in the alembic of glaſs is revivified; and in this experiment the fixed air is evidently produced from the charcoal, while the inflammable principle combining with the calx of lead, reſtores it's metallic form. The ſame reſult is obtained by diſtilling filings of zinc with fixed cauſtic alkali, ſhewing further the ſtrong affinity between the inflammable principle of charcoal and that of metal. On obſerving alone the great quantity of fixed air procured by diſtilling dried wood, one would naturally conclude, that this principle ought to be found in charcoal.

9. *The component principles of vital air are abſolutely unknown.*

No one has hitherto diſcovered the method of compounding, or forming from principles, vital air. Mr. Wieglib invites thoſe of a contrary opinion to the proof. Lavoiſier himſelf ſeems to think his proofs of (a pretended) oxigene combined with fire or light, as forming vital air, inſufficient.

In all the experiments where we find this air, it proceeds from the decompoſition of bodies, of which it was a conſtituent part: it appears, therefore, to be of an appropriate nature, and to be a conſtituent part of certain bodies: it may, poſſibly, be found in ſome acids, as is proved from the nitrous acid; but we ought not thence to give it the name of oxigene (acidifying principle), a name that might with greater propriety be attributed to fire.

10. *Fixed*

10. *Fixed air cannot be produced by an artificial combination.*

This propoſition is directly contrary to the obſervation of Mr. Lavoiſier, and the chemiſts who follow his ſyſtem, and if eſtabliſhed will overthrow it entirely: for if the fixed air that Mr. Lavoiſier obtained is not produced (*productum*) by the combination, but only ſeparated (*eductum*), the new ſyſtem falls to the ground, and their famous *oxigene* will turn out to be as chimerical as their political theories.

The propoſition before us has been ſufficiently proved by a ſeries of experiments, publiſhed by Mr. Green, in 1786,* and which have not been refuted by Mr. Lavoiſier, or any of the advocates of the French chemiſtry. Mr. Wieglib repeated the experiments of Mr. Green, and was perfectly convinced of their accuracy.

Of theſe we ſhall now quote ſome of the moſt remarkable. In the fourth and eighth of Mr. Green's experiments, he burnt ſome phoſphorus under a receiver filled with atmoſpherical air kept under water, and obtained an acid water which precipitated lime from lime-water, but contained no fixed air. Though Mr. Lavoiſier conſiders phoſphorus (without proof, however,) as a ſimple body, it is more probable you ſee that it contains an inflammable principle. If Mr. Lavoiſier's aſſertion had been well founded, phoſphorus ought in this experiment of Mr. Green's to have produced, with the particles of vital air, fixed air; but as neither Mr. Green nor Wieglib could obtain this air, we may conſider the French opinion as deſtitute of foundation; the lime is precipitated in this experiment by the phoſphoric acid diſengaged by the combuſtion.

In

* Obſerv. et Exper. circa geneſin aeris fixi et phlogiſt. Hallæ, 1786, in 4to.

In his eleventh and thirteenth experiment, Mr. Green burnt phosphorus, which was reduced in small pieces; in eight cubic inches of the purest vital air, after the combustion, there remained three eighths of a cubic inch of phlogisticated air, and the water contained no fixed air. These experiments prove the fifth proposition.

In the nineteenth, twentieth, twenty-first, and twenty-second, Mr. Green could not obtain fixed air by burning sulphur in atmospheric air.

In the twenty-fourth and twenty-fifth, Mr. Green proves that fresh prepared calx of lead contains neither vital nor fixed air.

Regulus of antimony, lead, zinc, sulphur, &c. exploded with nitre, produced no fixed air.

Vital and inflammable airs burnt together, gave no fixed air, which ought to have been the case if there was any foundation for Mr. Lavoisier's system.

Mr. Lavoisier's errors have been in a great measure occasioned by considering charcoal as a simple principle, without giving sufficient proofs for this opinion. Mr. Wieglib has shewn, that it must be considered as compound, and that in all the experiments where Mr. Lavoisier obtained fixed air, it was separated from the charcoal he used.

It has been said, "that there is no direct experiment to prove that fixed air is composed of pure air and phlogiston, and that unless this is properly supported, the presence of phlogiston in metals, in sulphur, and in nitrous air, must be given up." This reasoning is founded on a false principle, which seeks to combine fixed air with substances that only contain pure phlogiston; but what proofs have we that fixed air is a compound. If these reasoners had consulted the operations in nature, it would certainly have convinced them, that *by a combination*

bination of vital air with phlogiston we never obtain fixed air.

Mr. Wieglib, having proved the foregoing propositions, invites chemists to examine whether the system of *Stahl*, as now improved, is not conformable to truth? whether the experiments deduced from it are not more simple, more palpable, and more easy to explain, than by Mr. Lavoisier's new theory? He afterwards points out the sources that have led Mr. Lavoisier into error, traces the steps that have gradually conducted him to his present theory. But views of this part of his paper would lead farther than the nature of these Lectures will allow.

Thus I think you have seen that the inflammable principle still holds it's ground, and cannot be rejected, as the French have imagined, from the philosophy of nature. You are not "to expect that any one can present you with a handful of this principle, separated from an inflammable body; you might just as reasonably demand a handful of magnetism, or gravity, &c. to be extracted from a magnetic or gravitating body. There are powers in nature *which cannot otherwise become the objects of sense*, than by the effects they produce; and of this kind is the inflammable principle or phlogiston."

Wherever we turn, we find every operation in nature bearing testimony to the existence of *fire and light* in various forms, and giving us evidence of their incessant active energy. By their various modifications they are the principal instruments in constituting the peculiar and distinguishing properties of bodies. To their phlogistic principle metals owe their splendor, ductility, and elasticity. It abounds in vegetables; their colour, taste, and smell depend thereon. Though contracted views of the laws of nature have distinguished this active principle

principle by as many names as energies, yet is there great reaſon for concluding, that it is the ſame agent which we at one time contemplate in the form of concentrated light, tearing aſunder the denſeſt adamant, and at another rending the clouds, and threatening with reſiſtleſs deſtruction the lofty oak and towered citadel.

"There is hardly a body in nature in which this principle does not enter. Whether we caſt our eyes on the furniture of our houſes, or look abroad upon the trees in the foreſt, the beaſts in the field, the fiſh in the ſea, the ſea itſelf, or the mineral ſtrata in the bowels of the earth, this principle perpetually obtrudes itſelf on the eye of the philoſopher."

"There is hardly an object in nature but what conſiſts of it under different modifications, or combined with different baſes. The reſtoration of the calces of metals to their metallic form, by a junction with this principle, when obtained indifferently from almoſt every combuſtible body in nature, ſeems clearly to aſcertain the fact. It may, however, be worth while to convey ſome further idea of this matter by *analogy*, comparing the junction of *phlogiſton* with ſuch a variety of bodies to that *mephitic air*, which is believed to be latent, or fixed in a block of marble."

"Previous to Dr. Hale's and Dr. Black's diſcoveries reſpecting fixed air, it would have been as difficult to form any idea of ſuch latent or fixed air, as ſome now find it to conceive that a lump of wood, tallow, bees-wax, or iron, contains a large quantity of what is with propriety denominated latent or fixed fire."

"As fixed air has the wonderful property of entering into the ſubſtance of a block of marble or lime-ſtone, and of there lying hid in ſuch a manner as to be totally inconceivable to the under-

ſtandings of mankind, abſolutely loſing every appearance of air; ſo hath the ſolar ſubſtance the property of entering in a ſimilar manner into the ſubſtance of a vaſt variety of the objects of nature; but more eſpecially into every metallic earth or calx; thereby giving it it's metallic form, and continuing intimately combined with it, ſo as, without the aid of ſome chemical or mechanical proceſs, to elude both our feelings and the detection of the niceſt thermometer."

"As fixed air is capable of rendering the moſt cauſtic alkali or lime perfectly mild and harmleſs to the touch or taſte, ſo hath fixed fire the property of rendering ſome of the moſt corroſive and poiſonous metals equally mild and harmleſs. There is hardly any, from the ſtrongeſt concentrated mineral acid to the weakeſt vegetable one, but what will expel fixed or mephitic air from alkaline ſubſtances, combining with them into a variety of neutral ſalts. Some of the ſtronger mineral acids, and probably the vegetable, if properly concentrated, will alſo expel inflammable air from metallic ſubſtances, with which they alſo combine, forming a variety of neutral ſalts. They who deny the exiſtence of phlogiſton, may conſider this as merely a ſeparation of inflammable air from the different earthy or metallic baſes; but ſurely the inflammable air may with equal propriety be conſidered as the principle of inflammability, aſſuming, *in conjunction with water*, a new form, viz. that of air; for the higheſt concentrated acid, which we can uſe on theſe occaſions, contains a ſufficient quantity of water to form, in conjunction with phlogiſton or fixed fire, ſome proportion of that elaſtic fluid which we call inflammable air."

"If we attend ſtill more cloſely to this circumſtance, we ſhall be compelled to acknowledge that it is actually the caſe, for the moſt concentrated mineral

mineral acid muſt part with it's water upon it's particles uniting with thoſe of the ſolid metal. It becomes then, in fact, a caſe of double elective attraction; the acid and the metallic earth unite, the water quits the acid, and unites with phlogiſton in the newly-formed aerial compound; yet all the water cannot be diſpoſed of in this way, for a conſiderable portion of it enters into the metallic ſalt as it ſhoots into cryſtals, from which, by the application of a moderate heat, it may be expelled in it's pure ſtate, leaving the acid and metallic earth in the form of a ſaline powder."

"The quantity of phlogiſton which is fixed in a pound of any metal will occupy an immenſe ſpace when expanded, in conjunction with water, in the form of inflammable air. The ſame thing may be obſerved of the mephitic vapour which riſes from alkaline ſalts, and abſorbent earths, when they are mixed with an acid in a ſolid form; for here no fixed air will riſe. This is owing to the want of water to combine with the mephitic acid in the form of fixed air; for no ſooner is moiſture added, than the fixed air riſes copiouſly. And to this cauſe we ought alſo to aſcribe part of the loſs of weight, which was firſt obſerved by Dr. Black on the mixture of acids and abſorbent earths, or alkaline ſalts."

"Fixed air, as an *acid*, neutraliſes, and renders mild, the moſt corroſive alkali or lime. Dr. Prieſtley hath conceived phlogiſton to be the principle of *alkalinity;* and accordingly, like ſomething alkaline, we obſerve it, from whatever ſubſtance obtained, to form a junction with the moſt corroſive mineral acids, and to rob them of their activity as ſuch: thus the muriatic acid, that has been once uſed in making the corroded preparations of anatomiſts, is ſo nearly neutraliſed, and rendered inert, that it will not repeatedly anſwer that purpoſe,

pofe. The ftrongeft vitriolic acid lofes it's cauftic property in the fame manner, but more ftrikingly, by junction with oil, bees-wax, or tallow, which abound with phlogifton. As fixed air may, by art, be feparated from marble and lime-ftone, and may be made to appear evident to our fenfes; fo may the moft of this fixed fire be feparated, by art, rom the bodies which contain it, and become immediately obvious to our feelings, and to the detection of a thermometer."*

OPINIONS OF ANCIENT WRITERS.

It may be ufeful, and I think cannot be unpleafant, to lay before you the opinions of ancient writers upon the fubjects we have hitherto difcuffed in our Lectures: they had the fame opportunities that we have, and derived their knowledge of things from evidence and obfervation. How far they were capable of carrying their obfervations, it will be difficult to fhew with precifion: much farther, however, than feems to be allowed by many modern writers, who confider wifdom as a child newly born.†

There are innumerable appearances and operations in nature, which are fubjected to the eyes and fenfes of men, though unaffifted by philofophic apparatus; and as nature is confiftent with itfelf, from thefe we may form a judgment concerning their knowledge of phyfical principles.

The fkill of the ancients in mechanical arts is generally allowed, and monuments of it are ftill remaining, which their fons at this day would find it hard to exceed or even to imitate; their knowledge in geometry and mathematics is the foundation

* Medical Spectator, No. 12.

† For inftances of the knowledge of the ancients, fee Jones's Effay on the Firft Principles of Philofophy. See alfo Duten's Enquiry.

tion of our own, and perhaps modern times can find none ſuperior in theſe ſciences to *Archimedes*, *Euclid*, and *Apollonius*.

PLATO, who was the head and founder of the Academics, and who was without doubt the greateſt and moſt amiable philoſopher among the Greeks, aſſerts, " that *fire* and heat beget and govern all things;" where he deſcends to particulars, he accounts for the animal functions, *from an intertexture of air and fire* acting throughout the whole frame of the body. To *fire* he aſcribes the office of *expanding within*, and acting through the body outwards; while the element of *air compreſſes from without*, and counteracts the force of the internal fire. *By the miniſtry* of theſe cauſes, and the impoſſibility of a vacuum, a perpetual circulation is, as it were, kept up through the motion of the lungs in inſpiration and expiration. He imputes the effects, obſervable in amber and the loadſtone, in gravitating and projecting bodies, to the action of the ſame elements. For, in all theſe caſes, he obſerves, there is really no ſuch thing as attraction; but that the cauſes already aſſigned will be found, by thoſe who inquire diligently, to effect all theſe wonders of nature by their *reciprocal impulſes*.

In another place, ſpeaking of the mediation of elementary fire and light, he ſays, " Theſe are the *ſecondary and co-operating cauſes*, which *God* makes uſe of as *his miniſters* for the finiſhing and perfecting of his work. Moſt men look upon theſe as primary cauſes of all things, inaſmuch as they occaſion *heat* and *cold*, can effect the *coheſion* and *diſſolution* of bodies, and perform all other things.

In the Timæus, he ſhews, by ſtrong reaſons, that " it is neceſſary corporeal nature ſhould be viſible and tangible; but that nothing can be viſible without fire, or tangible without ſomething ſolid, and nothing ſolid without earth. Hence the

the Divinity composed the body of the universe from *fire* and *earth*; but it is impossible for two things alone to cohere together, without the intervention of a third; for a certain collective bond is necessary in the middle of the two." "But solids are never harmonized together by one, but always by two mediums. Hence the Divinity placed water and air in the middle of fire and earth, and fabricated them as much as possible in the same ratio to each other; so that fire might be to air, as air to water; and that as air is to water, so water might be to earth."

"*Water*, when it loses it's *fluidity* by concretion, appears to become stones and earth; but when liquified and dispersed, it forms vapour and air. Likewise *air*, when *burnt up*, becomes *fire*. And, on the contrary, *fire* becoming *concrete* and extinct, passes again into the form of air," &c. "And thus it appears they mutually confer on each other generation in a certain circular progression." Again, "It is necessary to understand that there are many kinds of fire, as for instance, flame, and that which is kindled from flame, which burns indeed, but exhibits no light to the eyes, and which, when the flame is extinguished, abides in the ignited nature." Again, "This departure of fire we denominate refrigeration; but the coalition which takes place when fire is absent, we call a concretion and a cold rigidity." "Fire entering into the void spaces of water, as water into those of earth, influences water, in the same manner as fire influences air, and becomes the causes of liquifaction to a common body." * From these passages, which might be further illustrated and confirmed, we find that the ancients were not ignorant of latent fire, or it's operations, and that they

* See Taylor's Translation of the Cratylus, Parmenides, and Timæus of Plato.

they diſcovered, by obſervation and attention to firſt principles, the principles of mind, what modern philoſophers have involved in obſcurity, and overwhelmed with doubts.

The ancient Platoniſts divided nature into two parts, one of which was *active*, the other *paſſive*. They held it impoſſible for bodies to *cohere*, unleſs they were kept together by ſome force, and it was neceſſary this force ſhould be exerted by *ſome matter*. In diſtinguiſhing the ſeveral uſes of the elements, they attributed to *air* and *fire* the power of giving motion, and cauſing effects; to *earth* and *water*, a paſſiveneſs or diſpoſition to receive their impreſſion. "Heat and cold, according to Ocellus Lucanus, the faculties of fire and air, are the cauſes and efficients; the dryneſs and moiſture of the earth and water afford them materials to work upon."

Zeno, the leader of the Stoics, taught that "nature was ſupported by an elementary fire diffuſed through all the parts of it; that there is no vacuity; the univerſe being ſo completely united in itſelf, that there is a connection and harmony between things terreſtrial and celeſtial."

Hippocrates, whoſe ſentiments upon air I have already communicated to you, ſpeaking of the element of *fire*, affirms, "that it diſpoſes all things in the body, after a manner proper and according to the ſimilitude of the univerſe, ſo that ſmall things are like to great, and great to ſmall; that it is moſt powerful, has an univerſal dominion, and governs all things according to the order of nature; while itſelf is ſilent, imperceptible in it's operations, and in perpetual agitation." This opinion will diſcover to you the whole ſecret of the Pagan idolatry. The corrupt philoſophers of the heathen world were well acquainted with the influence of theſe elements over all other things;

and

and being ignorant of the true and living God, judged it impoſſible that air and fire could perform ſuch wonders unleſs they were divine, and therefore worſhipped them univerſally as immortal and intelligent. Thus alſo the Chaldæans filled all ſpace with air, and what they called an all-nouriſhing æther, to which they joined an intelligent and life-giving fire.

The preceding Lectures have ſhewn you in what manner theſe inviſible agents, which were deified by the ancients, are uſed by DIVINE PROVIDENCE for carrying on the operations in nature: you have ſeen what great effects are produced therein by the *action of the elements on one another.* Their nature, properties, powers, and effects, are the genuine objects of *phyſiological* inquiry, and open ſo large a fund of entertainment and improvement, that the ſagacity of a Newton, if he were to live for a thouſand years, would never be able to exhauſt. Already the knowledge of the natural agency of the elements has been productive of conſiderable improvements in arts and manufactures. Indeed, no artificer can purſue his craft without ſeeing how neceſſary the elements are to aſſiſt him in his works, and how inſufficient manual labour would be without their concurrence. Great things have been already performed, and much more may be effected when they are farther underſtood and applied. *It is a capital diſtinction between natural and artificial operations, that nature penetrates, while art ſtops at the ſurface. Hence, if you would work as nature works, you muſt uſe the agents which nature uſes.**

You muſt alſo have obſerved, that in attaining one ſubject of knowledge, you acquired an imperfect information of others, concerning which you had no idea before. Hence one doubt is ſeldom

* Jones's Phyſiological Diſquiſitions.

dom ſolved without creating others. In your progreſs through ſcience, you will often clearly apprehend what remains a myſtery to others; while, on the other hand, you will be involved in difficulties they cannot diſcern.

It has been well obſerved by Dr. Prieſtley, that no philoſophical inveſtigation can be ſaid to be completed, which leaves any thing unknown and dubious on the mind. But ſuch is the neceſſary connection of all things in the ſyſtem of nature, that every diſcovery brings to our view new objects of diſquiſition and inquiry. The greater the circle of light, the more extenſive is the boundary of darkneſs.

As the *Divine nature* and the *Divine works* are infinite, you may promiſe yourſelves an endleſs progreſs in the inveſtigation; for the volume of the univerſe is perfect as it's author, and contains mines of truth for ever opening, fountains of good for ever flowing, or an endleſs ſucceſſion of brighter and more perfect exhibition of the power and wiſdom of our great and glorious God.* But ſuch being the volume of the univerſe, and ſuch it's author, do not preſume to judge thereof, with equal folly and raſhneſs, from a ſingle page exhibited to you, or to ſuppoſe that a little knowledge of philoſophy, or the management of a philoſophical apparatus, can ever prove detrimental to religion, or injurious to our eſtabliſhed church; ſuch is not the language of piety and learning, but the vapouring ſpirit of vanity, and the deluſive dictates of a ſelf-created importance. You muſt well know, without any information from me, that the ableſt advocates for free inquiry, and the greateſt promoters of experimental philoſophy, have been and are members of that church, which has been lately told to tremble at an air-pump, or an

* Hunter's Sermons on Divine Providence.

an electrical machine. Notwithstanding the selfish and party view with which men too often cultivate the fields of science, you may still discover, in every instance of it's progress, some of the steps of that vast plan of Divine Providence, to which all things are converging; namely, the bringing all his creatures to a state of truth, goodness, and consequent happiness; an end worthy of the best and wisest beings, and which we may perceive to be gradually effecting, by the advancement of knowledge, the diffusion of liberty, and the removal of error, that truth and virtue may at last shine forth in all the beauty of their native colours. Eternal love, slow as it may seem in it's steps to us of mortal race, is unwearied in it's motions, and inexhausted in it's distributions; and as it can never cease to shine, it should never fail to animate you with it's present influence, and the sublime and glorious prospect of it's increasing strength and ever-growing splendor.

END OF VOL. I.

DESCRIPTION

OF

THE FIGURES

IN THE

PLATES

BELONGING TO VOL. I.

OF

LECTURES ON NATURAL PHILOSOPHY.

DESCRIPTION
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FIGURE 1, plate 1, is a perspective view of *a double-barrelled air-pump*, according to the construction of the *Rev. Mr. Prince*, of Massachuset's States, America. The peculiar advantages and properties of this construction have been already explained in the appendix to Lecture III. The principles of the air-pump have also been, I hope, sufficiently elucidated in the Lectures on Air, so that I have here only to describe the apparatus delineated in the several plates of this volume: of these, the air-pump is certainly a most important instrument, not only from the entertainment it affords, but also for the light it throws upon this branch of science. This figure represents the air-pump with a receiver on the plate, and barometer gage, as ready for use; A, A are two brass barrels in which the pistons move; the barrels communicate with the receiver, placed on the plate of the pump by means of the pipe B, C, and canal D, E; the stems or rods of the pistons are seen at F, G; each of these is connected with a rack, that is, a piece having teeth on one side. At I there is a wheel, whose teeth take into those of the rack; so that by turning the handle H, fixed to the axis of this wheel, one way or the other, the racks, and of course the pistons connected with them, are alternately raised and depressed, by which means the air will be exhausted out of the receiver K, L, the tube B, C, and the canal D, E, which as they communicate with each other, may all be considered as one vessel. At the top of each barrel is a plate, on which is a box m, n, containing a collar of leathers; through this the cylindrical part of the piston rod moves, air tight; o, o is the place of the valve on the top plate, into which a pipe is soldered that conveys the air from the valves to the duct going under the valve pump. P represents the valve-pump, designed to prevent the pressure of the atmosphere from acting on the valve on the top-plate. Q is the piston-rod of this pump, R the handle by which it is worked. Y is a cock to cut off occasionally the communication between the receiver and the working parts of the pump.

 There

There is a ſcrew at S, which cloſes the orifice of the canal D E: by unſcrewing this the air may be admitted when required. Z is an oil-veſſel to receive the oil driven over by the action of the pump. It may be proper to obſerve here, that there ſhould always be a ſmall quantity of oil in the cups of the boxes m, n, that hold the collar of leathers through which the piſton rod moves: abc is the barometer gage; de the box or ciſtern containing the mercury; there is a divided box ſcale affixed to the tube to aſcertain the riſe or fall of the mercury; a ſmall ivory tube encompaſſes the lower end of the glaſs tube, and floats upon the quickſilver in the ciſtern; the upper end of this is always to be brought to coincide with the lower diviſion of the box ſcale; this it is made to do by the ſcrew underneath the ciſtern: when it thus coincides, the diviſions on the ſcale give the true diſtance from the ſurface of the mercury in the baſon.

F is a key for tightening or looſening the ſcrews of the pump.

Having already in the appendix to Lecture III explained the principles on which this pump acts, I have only to obſerve here, that as when either piſton is down, there is a free communication from the receiver through the tubes and canal to the part of the barrel above the piſton; when the piſton riſes, it forces out all the air above it through the valve in the top plate; and as this valve prevents the air from returning into the barrel, when the piſton deſcends, a vacuum is formed between it and the under ſurface of the top plate; as ſoon, therefore, as the piſton has deſcended below the holes communicating (by the tubes and pipe) with the receiver, the air ruſhes therefrom into the exhauſted barrel; on the next aſcent of the piſton this air is forced out as before. To prevent the piſton from meeting any reſiſtance in it's deſcent, there is a valve therein to allow the air to paſs through as the piſton deſcends, but the air does not neceſſarily depend upon a paſſage through the piſton in order to get into the barrel. By this means the piſton deſcends as eaſily as in any other conſtruction, while the valve therein does not impede the rarifaction. The valve-pump is, as has been before obſerved, uſed to take off the preſſure of the atmoſphere from the valve on the top plate of the pump, and form a more perfect vacuum between this plate and the piſton, that nothing may prevent this inſtrument from exhauſting as far as it's expanſive power will permit.

The *barometer gage* abc, which is uſed to meaſure the exhauſtion of the receiver, conſiſts of a tube (divided by a ſcale annexed to it, of inches, and fractional parts of an inch), whoſe higher orifice communicates with the receiver, the lower is immerſed in a ciſtern of mercury.

Before any exhauſtion has taken place, the mercury in the tube and ciſtern is upon the ſame level; and, after any number

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of turns of the pump, the air in the receiver and tube is equally rarified, and the mercury will aſcend in the tube till the weight of the column above the ſurface of the mercury in the ciſtern, and the elaſticity of the air in the receiver, taken together, be equivalent to the weight of the atmoſphere; and if the altitude of the column is equal to the ſtandard altitude, the vacuum in the receiver, and that above the mercury in the barometer, are the ſame.

Fig. 11, plate 1, is a ſyphon-gage, which is occaſionally ſubſtituted for the barometer-gage. Fig. 12, plate 1, is the pear gage, deſcribed p. 116.

Fig. 4, 5, 6, 7, 8, are different kinds of valves. In fig. 4, the hole is covered with a piece of oiled ſilk, which is confined looſely to the top of the plate, ſo as to be opened eaſily by the air acting from beneath; fig. 5, a hemiſphere of braſs, fitting a concave hemiſphere; this has been occaſionally applied in pump work; fig. 6, a conical valve, this has been applied to the air-pump; fig. 7, is a flat piece of braſs lying over the holes, through which the water is to paſs; it is preſerved in it's poſition by the two ſide pieces, or ears g, h, through which the pins i k paſs; fig. 8, is the common water-valve, conſiſting of a plate and leather hinge.

Fig. 2, plate 1, gives us a view of the *common table air-pump*; A, A, are the two barrels of braſs; theſe are firmly retained in a perpendicular ſituation to the ſquare wooden table E F G H, by the tranſverſe beam T, T, which is preſſed upon them by the ſcrews O, O, at the top of the two pillars N, N: from the hole in the center of the pump-plate, there is a perforation or canal in the braſs piece D to the fore part K, where a ſcrew is fixed to let in air occaſionally: from the above-mentioned canal there is a perforation at right angles to the former, going to the center of the baſis of each barrel; at each of theſe centers a valve is placed opening upwards to admit the air into the barrels; there is a piſton, ſo fitted to each barrel, that the air cannot paſs between it and the ſides of the barrel; to each piſton there is a valve opening upwards, that the air in the lower part of the barrel may eſcape through them into the common air; they are alſo connected to a rack, and are raiſed or depreſſed by a handle, the lower part of which is fixed to the axis of a cog wheel, whoſe teeth take into the rack; one piſton is raiſed, and the other depreſſed, by the ſame turn of the handle.

Two barrels are advantageous, not only as performing the work quicker, but alſo becauſe the weight of the atmoſphere, preſſing upon the riſing piſton, is counter-ballanced by the ſame weight preſſing upon the other piſton deſcending.

I have ſhewn you in the *Lectures on Air*, that the operation of air depends on the *elaſticity* thereof. When either of the piſtons is drawn upwards, a vacuum is left behind it, and the

preſſure being thus removed from the valve in the bottom of the barrels, this valve will be opened by the elaſticity of the air in the receiver, and the air, ruſhing through it, will be uniformly diffuſed through the receiver, the canal connecting this with the lower valve and through the barrel. But upon depreſſing the piſton, the valve at the bottom of the barrel will be cloſed, and the air therein being condenſed, will open the valve in the piſton and eſcape; thus the air contained in the barrel is diſcharged, and, by every turn of the winch, a quantity of air equal to the contents of the barrel, and equally denſe with that in the receivers, is exhauſted.

Behind the large receiver L M there is a ſmall plate for ſuſtaining a ſmall receiver P O; from the hole at the center of this plate there is a canal communicating with that which goes from the large receiver to the barrels; under the receiver is a ſmall bottle containing mercury, a ſmall tube filled with mercury, and freed from air, and inverted with the open end in the mercury: this is called the *ſhort barometer-gage*. As the air is taken out of the receiver P O, at the ſame time as it is taken from the larger one L M, the deſcent of the mercury in the tube will point out the degree of rarifaction in the receivers; the mercury does not begin to deſcend in this tube till near three-fourths of the air have been extracted; and the air is ſaid to be as many times rarer than the atmoſphere as the column of mercury, ſuſtained in this tube, is leſs than the height; the mercury ſtands at that time in a common barometer.

Fig. 3, plate 1, is a ſmall pump with a ſingle barrel, and two plates, one for receivers, the other for a ſhort barometer-gage. This pump acts upon the ſame principle as the one laſt deſcribed, and is conſtructed in the ſame manner, excepting that it has only one barrel, and that the piſton is moved merely by the hand; a deſcription thereof muſt be ſuperfluous.

Fig. 16, plate 1, repreſents a plate with a box, containing a collar of leathers, and a wire adapted to ſlide through this collar.

I have ſhewn, p. 121, that when accuracy is required, the receiver ſhould not be placed upon leather, either oiled or ſoaked in water. I would here add, that in all caſes it is better to rub the edge of the receiver with a tallow candle, letting the tallow be nearly as thick as a ſhilling thereon. I think, that upon the whole, this method is leſs dirty and diſagreeable than that of uſing oiled leathers; for it is eaſy, on removing the receivers, to place them on a ſheet of paper till they have been cleared.

With reſpect to the leathers uſed to accommodate the receivers to the plate of the pump, and make the junction air-tight, they are either ſoaked in water or oil, or in a mixture of bees-wax and hog's lard. Either ſoaked leathers or tallow are

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to be placed wherever a plate is fitted on a receiver, or in any caſe where two pieces are to be joined together and rendered air-tight.

Experiments to shew the expansive Power or Elasticity of the Air.

Take a bladder and preſs the air out of it, then tie the neck cloſe, and ſuſpend the bladder under a receiver, place the receiver on the plate of the pump, exhauſt it, and the bladder will be expanded and blown up by the ſpring of the ſmall reſiduum of air: on admitting the air, the bladder will ſhrink into it's former ſhape. A bladder thus expanded, after the air is withdrawn, is repreſented fig. 10, plate 1.

Two experiments are generally made with the apparatus called a bolt-head and jar, fig. 18, plate 1; it conſiſts of a glaſs ball A, of about an inch diameter, with a ſtem from 3 to 4 or 5 inches in length, and a ſmall bottle or jar B, filled about two thirds with water.

Place this apparatus on the pump, and cover it with a receiver, exhauſt the air, and the preſſure thereof will be removed from the ſurface of the water in the bottle; and the air in the bolt-head, having nothing to counteract it's exertions, expands and eſcapes through the water in the form of large round bubbles of air. Let the air into the receiver, and it's preſſure on the ſurface of water will force this into the bolt-head, for as the greater part of the air was taken away, the ſpring of the remainder was weakened; it therefore yields to the compreſſing force of the external air acting on the water, and ſuffers it to enter till it is ſo far compreſſed as to be equally denſe with the external air, and capable of exerting the ſame degree of elaſticity. The bulk of this bubble of air, compared with the bulk of the bolt-head, ſhews what portion of the whole quantity of air remained after exhauſtion.

Fill the bolt-head almoſt full of water, leaving only a very ſmall bubble of air; then inverting it, immerge the ſtem in the bottle of water, and place the whole under a receiver: on exhauſtion, the ſmall bubble of air will expand itſelf, and force all the water out of the bolt-head; the preſſure of the air by which the water is retained in the bolt-head being removed, the ſpring of the air exerts itſelf, and expels all the water.

We have another inſtance of the elaſtic force of the air, and it's action, when freed from incumbent preſſure, by the expanſion of the bubble contained in the great end of an egg between the ſkin and the ſhell; for on making a ſmall hole in the little end, and inverting it in a glaſs, the bubble of air will force out the contents of the egg through the ſmall hole in the lower end.

Break off evenly about one third part of the ſhell at the ſmall end of an egg, and let out the white and yolk; you will then perceive at the bottom, the bubble of air that lies between the ſkin and the ſhell; ſet the egg on a ſmall glaſs, place this upon the plate of the pump, and a receiver over both; then exhauſt the air, and the air in the ſhell will ſo expand itſelf as to raiſe up the ſkin, fill the ſhell, and make it reſemble an entire egg. This will ſucceed only when the egg is new, for the elaſticity is deſtroyed when the egg is ſtale.

Take a ſmall ſquare glaſs bottle whoſe ſides are very thin, but whoſe mouth is ſo cloſed by a cork covered with wax, that no air from within can eſcape; put it under a receiver, and then exhauſt the air therefrom, and the ſpring of the air within, not being counteracted by any external force, will expand itſelf with ſuch force as to overcome the ſides, and burſt the bottle in pieces. In making this experiment, you ſhould place a piece of thick paper or leather on the plate of the pump, to prevent it's being injured, fig. 2, plate 3. If the ſame experiment be made with the bottle and a cage over it, under water, the ſhock will be ſo great as to ſhake the whole pump.

Fig. 13, plate 1, repreſents a glaſs veſſel, over one end of which a bladder has been tied; it is placed on the plate of the pump with a receiver over it; when the air is drawn out of the receiver, the ſpring of that included in the veſſels ſtretches the bladder ſo as to burſt it in pieces. The bladder uſed in this experiment ſhould be thin.

Plate 2, fig. 6, is a number of heavy leaden weights, kept ſteady by means of a braſs frame with three pillars; they preſs upon a bladder half blown, and placed under them; this apparatus is to be put on the pump with a receiver over it; on exhauſting the air, the expanſion of that in the bladder gradually raiſes the weights; on admitting the air, the bladder ſhrinks, and the weights deſcend to their original ſituation.

ON THE SPRING OF THE AIR IN THE PORES OF BODIES.

Place a ſhrivelled apple on the plate of the pump, ſet a receiver over it, and exhauſt the air; this will give liberty to that which is within the pores of the apple to expand, and ſwell out the ſkin, removing it's ſhrivelled appearance: on letting in the air, it reaſſumes it's former ſtate of decay.

Fix ſome lead to a piece of cork, ſo as juſt to ſink it in water; when this is placed under an exhauſted receiver, the air in the pores of the cork expands ſo as to ſwell it, and thus render it lighter than water, and it conſequently riſes to the top and ſwims: on the re-admiſſion of the external air, the cork is preſſed down and ſinks again; the globules of air that ſtand upon the ſurface of the cork afford a pleaſing ſight, they appear like

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the pearly drops of dew on the piles of grafs; they difappear on letting in the air.

Put fome beer or ale into a tumbler, and place it under a receiver on the plate of the pump; in working the inftrument, the air in the beer will expand itfelf, and rife up to the top of the jar in a large white head of froth: this frothy appearance is occafioned by the tenacity of the fluid, which prevents the bubbles of air from efcaping as foon as they rife; when the air is re-admitted, the air-bubbles contract and fubfide. On tafting the beer, you will find it has loft all it's fpirit.

In the fame manner, if warm water be placed under a receiver, on exhaufting the air an ebullition will take place; fmall air-bubbles will firft rife; thefe will foon be fucceeded by larger ones, moving with fuch rapidity as to agitate the water, and give it all the appearance of boiling.

If you put an egg into a tumbler of water under a receiver, on exhauftion, you will fee the air in a very beautiful manner rife in fmall jets through the water from the pores of the egg. The fame appearances may be pleafingly obferved with other fubftances, as moft vegetables, or a piece of wood of any fort, when immerfed in a jar of water under a receiver.

Fig. 8, plate 2, reprefents a fountain that is made to act by the fpring of the included air. It confifts of a bottle partly filled with water, the upper part is occupied by the air which cannot efcape, as the cover is air-tight; a glafs tube, long enough to reach nearly to the bottom, is cemented to the brafs cover; there is a fmall hole in the cover directly over the bore of the tube. This bottle is placed on the plate of the pump with a receiver over it. When the external preffure is leffened, the included air will fo prefs on the furface of the water as to force it through the glafs tube and hole in the cover, from whence it will rife in a pleafing jet of water.

Fig. 7, plate 2, is another apparatus for the fame experiment; but here the water is prevented from falling on the pump plate, by means of the glafs cover a b; a fmall hole is drilled in this cover to permit the efcape of the air.

Fig. 2, plate 2, is a fmall apparatus acting upon the fame principles, and defigned to illuftrate the fame phenomenon; the cafk is nearly filled with coloured water, on the top of the cafk is a head, from the mouth a glafs tube proceeds, paffing through the cafk, and terminating a fmall diftance from the bottom; there is another tube from the neck which proceeds downwards, and enters a fmall way into the barrel: when this is placed under a receiver, and the air exhaufted, the fpring of the air preffing on the water, forces it up the tube through the mouth, from whence it defcends by the other tube into the barrel. To render this more entertaining, a bladder is tied under the neck with only a fmall quantity of air therein; this

is covered with a ſmall ſhirt; when the preſſure of the air is removed, the bladder expands and ſwells out the ſhirt, which, to an ordinary obſerver, ſeems occaſioned by the liquor drank by our Bacchus.

Fig. 11, plate 3, is an apparatus deſigned to ſhew that the ſpring of the air acts with a force equal to the preſſure of the air, by raiſing a column of mercury to the ſame height. A is a bottle, nearly filled with quickſilver; B C a tube on which a ſcrew is cemented, to ſcrew into the top-part of the bottle, the lower part of the tube deſcending nearly to the bottom thereof; D F E is a receiver and large tube to go over this apparatus, when the whole is placed on the pump-plate. You will perceive, in proportion as you exhauſt the air, that the mercury riſes in the tube by the ſpring of the included air, till it attains the ſame height as the mercury in the barometer; thus proving that the ſpring of the air operates with the ſame force as the preſſure.

In the jar under the receiver, fig. 13, plate 2, are repreſented two hollow glaſs images, with ſmall balloons of glaſs over their heads; theſe are ſo far filled with water as to make them ſink therein; on exhauſting the air, they riſe to the top and ſwim; part of the balloon is occupied by air, which expands on the removal of the external preſſure, and drives out part of the water, by which means the images and balloon are rendered lighter than the water, and riſe accordingly; on re-admitting the air, the water re-enters, and they ſink as before.

In the ſame manner, a bladder nearly emptied of air, and ſunk by a ſmall weight to the bottom of a jar of water, will, upon exhauſtion, expand, become ſpecifically lighter, riſe to the top, and ſwim.

Fig. 9, plate 3, repreſents what is uſually, but very improperly, called the lungs-glaſs. A bladder is tied round a ſmall pipe from the cover; when this apparatus is placed under a receiver, and the air partly withdrawn from the bladder through the hole at a, the ſpring of the ſurrounding air in the bottle, which cannot eſcape, compreſſes the bladder; when the air is let in, the bladder expands; and theſe motions have been ſuppoſed analogous to thoſe of the lungs.

EXPERIMENTS ON THE PRESSURE OF THE AIR.

Place the braſs cone on the plate of the pump, and cover it with the hand, then exhauſt the air from it, and by this means the counter-ballance being removed from below, the air will preſs upon the hand with a vaſt weight, and a conſiderable part of the palm will be forced into the glaſs, and thus occaſion a ſenſation of ſucking. Now as the other parts of the hand have a greater preſſure

preſſure on them than that part which is under the receiver, and expoſed to the vacuum, the fluids in the body will be driven towards the part under the glaſs, and cauſe this part to ſwell and be ſtretched out; but this is alſo increaſed by the elaſticity of the air contained in the fleſh, which will expand and diſtend the fleſh when the external preſſure is removed.

Place a receiver on the plate of the air-pump, exhauſt the air from it, and the receiver will be ſo preſſed down againſt the plate by the external air, that it will be exceedingly difficult to ſeparate it from the plate of the pump without re-admitting the air; this will not appear ſurprizing when we conſider that the glaſs is preſſed down with a force equal to as many times fifteen pounds as there are ſquare inches which are covered by the opening at the bottom of the receiver.

To prove that the receiver is held down by the preſſure of the air on it's external ſurface, and not by any ſuction, in fig. 17, plate 1, you have an apparatus repreſented, which is deſigned to prove that the receivers, &c. are not confined to the pump-plate by ſuction, but by external preſſure. To effect this, the air is firſt exhauſted from the two receivers, you then let down the ſmall receiver upon the plate, by means of the wire paſſing through a collar of leathers, when it will be looſe and eaſily removed, but on letting the air in rapidly it falls upon the ſmall receiver, and fixes it upon the plate.

Fig. 14, plate 1, is called the bladder-glaſs. A bladder is tied over the upper end, the under end is placed on the plate of the pump; by exhauſting the air, the ſpring of the internal air is weakened, the bladder, yielding to the external preſſure, puts on a concave figure, and this increaſes till the ſtrength of the bladder is overcome by the incumbent weight, when it burſts with a very great report.

Fig. 15, plate 1, repreſents a piece of thin flat window glaſs, placed upon a braſs cone, and ſet on the plate of the pump; on exhauſting the air, the glaſs will be broke to pieces, like the bladder in the preceding experiment.

Fig. 2, plate 3, ſhews the mode of breaking a thin ſquare glaſs bottle by the preſſure of the air; on the top of the bottle is a valve, that, when the air has been extracted, it may not return; the bottle is placed on the plate of the pump, over it is a wire cage; this is covered with a receiver; the air is firſt to be exhauſted, and then ſuddenly admitted, when it's preſſure will break the bottle, reducing it inſtantly into very ſmall pieces.

Fig. 20, plate 1, is Otto Guerick's hemiſpheres, one placed on the other; the joint is rendered air-tight by a wet leather placed between them, or by a luting of tallow; the ſcrew A is to be ſcrewed into the hole at the center of the pump-plate, and the ſtop-cock placed as repreſented in the figure, that there may be a free communication between the hemiſpheres and the barrels of

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the inſtruments; exhauſt the hemiſpheres; then turn the cock to ſhut out the communication with the open air; when it is taken off, unſcrew it from the pump, and you will find the hemiſpheres are preſſed together with a very extraordinary force, a force equal to 15 lb. for every ſquare inch: this of courſe is more or leſs according to their diameter. To inveſtigate this by experiment, you may make uſe of a ſtrong ſteelyard, ſee fig. 19, plate 1. It is uſual to ſtate the preſſure at 15lb. for a ſquare inch. If the diameter be four inches, the area is 12.55 ſquare inches, which multiplied by 15, gives about 188 lb.

The exhauſted hemiſpheres will fall aſunder of themſelves in vacuo.

Fig. 9, plate 1, is a ſolid ſyringe, that is, one which has no hole at bottom; a heavy leaden weight is fixed to the bottom of the ſyringe; if the weight be drawn down in the open air, it will be forcibly driven back by the upward preſſure of the air; but in vacuo, where this preſſure is removed, it will deſcend. The handle of the piſton is to be ſuſpended from the hook belonging to the plate with a collar of leathers.

Fig. 22, plate 1, repreſents the apparatus deſigned to ſhew, that water riſes in pumps by the preſſure of the air. The part A B, is the model of the working part of a common pump; at the lower part of this is a braſs plate to reſt upon the receiver C D; from the center of this plate there is a glaſs tube which deſcends into the jar of water when the model is worked; before the air is exhauſted the water flows freely from the ſpout, but when the air is well extracted none can be obtained thereby.

Fig. 21, plate 1, deſigns of the common and forcing-pump.

Fig. 12, plate 2, repreſents what is called a *transferer*; it is fixed to the pump-plate by means of the ſcrew B. A receiver is placed on the plate of the transferer, and may be exhauſted, by turning the cock C, ſo as to open the communication between it and the pump; when exhauſted, it may be removed from the pump by turning the cock at right angles to it's former ſituation, to prevent any communication with the open air when it is removed. To make, with this apparatus, an artificial fountain in vacuo by the preſſure of the air; place a tall receiver on the transferer, exhauſt it, and remove the transferer from the pump, ſcrew the pipe to the lower part of the transferer, immerge this pipe in water, turn the cock, and the preſſure of the air will throw the water up into the receiver in the form of a fountain.

To prove that the mercury in the barometer is ſuſtained, uſe the apparatus fig. 11, pl. 3, already deſcribed; with this difference, that the ſmaller tube that enters into the bottle was open at top in the former caſe; but in this it is hermetically ſealed; there the tube was empty, here it is a barometer containing the mercury ſtanding in it at the proper height for the time;

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the lower end of the tube being immerged in the mercury in the bottle, place the apparatus on the pump; on exhausting the air, the mercury will gradually descend till it is on a level with the mercury in the bason; for as the density of the air diminishes, the elasticity decreases, and consequently the force which supported the mercury decreases. On re-admitting the air, the mercury rises to it's former height.

Fig. 11, pl. 3, represents what is called the *double* transferer. This has been sufficiently described in page 15. Screw the end of the pipe of the double transferers into the hole of the pump-plate, and turn the three cocks, that the communication may be opened between all the three pipes, E, F, D D, and the trunk; cover the plates with leathers which have holes at their centers, place a close receiver upon one plate, then shut the communication between the pipe F, by turning the cock, and exhaust the receiver; then turn the cock *d* to shut out the communication with the air, and unscrew the apparatus from the pump, and screw it on it's wooden foot; then put a receiver upon the other plate, this receiver will continue loose on the plate as long as it keeps full of air, which it will do until the cock be turned again to open the communication between the pipes and through the tube; and then the air in the receiver having nothing to act against it's spring, will flow until it is so divided between the receivers as to become of equal density in both, and they will be held down with equal forces to their plates by the incumbent pressure of the atmosphere; though each receiver will be kept down with only half the force that pressed upon the first, when it was exhausted of air, because it has now one half the common air which filled the other receiver, when it was set upon the plate; and therefore a force equal to half the force of the spring of the common air, will act within the receivers against the whole pressure of the atmosphere on the outside.

MISCELLANEOUS EXPERIMENTS.

Set a clean receiver upon the plate of the pump, and begin to exhaust it; then hold a candle to the side of the receiver opposite to your eye, several colours like a halo will appear about the candle; these colours are perceived at the beginning of the exhaustion; the appearance is occasioned by the vapour which rises from the wet leathers, and the refraction of the light through these vapours.

Fig. 5, pl. 3, represents the pipe for burnt air; place this on the top of an open receiver, and exhaust the air as usual; then place the end of the pipe in the middle of a charcoal fire, and open the cock; the deleterious air from the charcoal will then pass through the pipe into the receiver: remove the pipe from the receiver, and let a small piece of wax taper down into it, which will immediately go out.

Place

Place a candle lighted under a tall receiver; on exhausting the air, the candle will go out, and the flame will ascend to the receiver.

The flame would be soon extinguished in a close receiver, though the air is not exhausted.

The small apparatus, fig. 6, pl. 3, is to be placed on the top of a tall receiver, and a red-hot iron laid on a stand upon the pump plate; exhaust the air, and then let fall a few grains of gunpowder on the iron, where it will melt and dissolve, but not flash and explode: the receiver should be again exhausted before any more grains of powder are let down.

A B, fig. 9, pl. 2, is a ballance, to one end of which is suspended a piece of lead which is in equilibrio with a piece of cork at the other end of the beam. Place the beam and stand under a receiver, and having exhausted the air, the cork will preponderate; for as it's bulk is greater than that of the piece of lead, it must be more sustained by the air: re-admit the air, and the equilibrium is restored.

For as bodies which are immerged in fluids are known to lose a part of their weight, equal to the weight of a quantity of the fluid of the same bulk with the immerged body, consequently bodies of different specific gravities, which are in equilibrio in air, will not be so in vacuo; for here they will gain that weight which they lost in air, and the body of the greatest bulk will gain the most.

Fig. 10, pl. 2, is a more elegant apparatus for the same purpose.

Fig. 10, pl. 3, represents the guinea and feather apparatus.

When the air is exhausted from the receiver, turn the milled nut, and the piece of gold, and the feather which lay upon the piece underneath, will fall at the same instant, and descend in the same time to the bottom.

The eye of the observer should be fixed to the bottom of the receiver, to ascertain accurately the coincidence of descent in the two bodies.

From this experiment it is inferred, that bodies are attracted towards the earth with forces which are in proportion to the quantity of matter they contain, but not to their bulk; for if we suppose a guinea to contain 1000 times more matter than the feather, it will require 1000 times more force than the feather to move it through the same space in the same time.

Put two or three small pieces of phosphorus in an equal but small quantity of a mixture of oil of vitriol, oil of tartar per deliquium, and oil of cloves; this mixture will flame in the open air, but is easily put out with a little water: it shines, boils, and flames in vacuo.

Write

Write upon paper with ſolid phoſphorus, and then lay it on the plate of the pump with another piece of paper under it, place a receiver over theſe and exhauſt the air, the phoſphorus will gradually brighten in a dark room, and throw up a lucid cloud to the top of the receiver.

Fig. 15, pl. 2, is a common bell apparatus for ſhewing that air is a medium of ſound. Fig. 16, a more elegant apparatus for the ſame purpoſe, as it is ſet in action only by pulling up the wire that paſſes through the collar of leathers.

Pl. 4, fig. 11, illuſtrates the nature of echoes. See page 178.

Fig. 5, 6, 7, 8, 9, 10, plate 4, are deſigned to illuſtrate the motion of muſical ſtrings. See page 181.

F. 14, pl. 4, repreſents a ſyphon. Fig. 20, pl. 3, Tantalus's cup. See page 94, 95.

Fig. 2, pl. 4, is to explain the cauſe of intermitting ſprings. See page 96. Fig. 4, pl. 4, an apparatus for the ſame purpoſe. See page 97.

Fig. 1, pl. 4, a bent tube to illuſtrate the laws of the air's elaſticity. See page 51.

Fig. 3, pl. 4, for experiments on the rarifaction of the air by heat. See page 66 and 67.

Fig. 8, pl. 3, repreſents the apparatus for weighing air. It conſiſts of a ſtrong copper veſſel B, a beam A, C, and a ſtand for the beam. To exhauſt this veſſel, unſcrew the cap D, then ſcrew that end of the veſſel to the hole in the pump-plate, work the pump till you find by the gage that the air is extracted; you may then unſcrew the veſſel, put on it's cap, and ſuſpend it to the beam. The difference between the weight of the veſſel now and before it was exhauſted, gives the weight of the air it contains. The air cannot re-enter when the veſſel is taken from the pump-plate, becauſe there is a valve at the upper part.

Fig. 7, pl. 3, repreſents the mode of ſtopping a bottle in vacuo.

Fig. 21, pl. 3, repreſents an apparatus for letting any powder or liquid into a veſſel after it has been exhauſted.

Fig. 22, pl. 3, an apparatus for mixing different fluids in vacuo.

The nature and uſe of the three foregoing articles may be ſo eaſily conceived from the reſpective figures, as to render a deſcription unneceſſary.

Fig. 14, pl. 2, is a transferer and receiver, placed on a large receiver, in order to produce a vacuum ſuddenly; for this purpoſe the under one is to be exhauſted, you then turn the cock, and the air by ruſhing out of the ſmall receiver, will be conſiderably and ſuddenly rarified: the degree of rarifaction will be in proportion to the difference between the capacities of the two receivers.

CONDENSING MACHINE.

Fig. 1, pl. 2, repreſents a condenſing machine, or inſtrument to compreſs the air. A B is a ſtrong glaſs receiver, fit to receive and bear the preſſure of the air when conſiderably condenſed. C D is the ſyringe by which the air is thrown into the receiver: to work this you pull up the piſton above the hole, which admits the air to enter and fill the barrel of the ſyringe; the piſton being preſſed down, forces the air through a valve at the bottom of the barrel, from whence it paſſes up the tube into the receiver, but cannot return on account of a valve at the bottom of the barrel. E is the gage, which conſiſts of a glaſs tube open towards the tube F G, but hermetically ſealed at the other end. A ſmall quantity of quickſilver is left in this tube, which is preſſed towards the ſealed end on every admiſſion of air, and therefore determines by the proportion between it's original diſtance from F, and the diſtance when in a ſtate of compreſſion, the proportional denſity of the included air to that of common air; for as the air preſſes the quickſilver forwards, it ſhews the reſiſtance of the included air, whoſe denſity is always inverſely as the ſpace it occupies; the receiver is confined down to the plate by the tranſverſe piece G H, which is maintained in it's ſituation by the ſcrews I K L M; is a thick braſs plate to cover the top of the receiver; it is furniſhed with a wire paſſing through a collar of leathers. A cage is ſometimes placed over the receiver to prevent any accident, if the glaſs ſhould be burnt by the receiver.

Fig. 13, pl. 3, is the view of a fountain which is made to act by condenſed air; there is a pipe which deſcends almoſt to the bottom of the veſſel, the veſſel is to be nearly filled with water, then the ſtop-cock and pipe are to be ſcrewed into their place, and the ſyringe ſcrewed on the ſtop-cock; by this you charge the veſſel with air: then turn the cock, remove the ſyringe, and place either of the jets thereon. The fountain is often furniſhed with a baſon to receive the waſte water.

Fig. 19, is an agreeable jet that ſupports a ball on the top, dancing on the crown of the jet. Fig. 15 is a jet from which the water ſpouts, ſo as to form a kind of fluted column. Fig. 12, 14, 16, are jets of different forms. On the top of the fountain is placed a jet in the form of a croſs, the lower part ſcrews to the fountain, the upper part has eight jets, a, b, c, d, e, f, g, h. The jets a, b, ſpout horizontally; the jets c, d, vertically upwards; thereby forming two ſquares, one on each ſide of the upper part of the croſs, and meeting each other in a point, in which point the vertical jet is prevented from mounting higher by the action of the horizontal jet, while this is alſo prevented from proceeding horizontally by the action of the vertical jet, ſo that

that the ſtream aſſumes a different direction, at firſt intermediate, but afterwards falls into a parabolic curve. The ſame may be ſaid of the other vertical and horizontal jets. Fig. 5, pl. 2, fountain of command, deſcribed page 21. Fig. 4, pl. 2, the anti-guggler, deſcribed page 22. Fig. 3, pl. 2, a double funnel; it is uſually made of tin doubled; it is firſt to be filled to the brim with water, ſtopping the end of the pipe with the finger; the fluid riſes at the ſame time into the vacancy or hollow between the plates; the air included in the vacancy paſſing through a hole which is generally concealed under the handle, this muſt be ſtopped when the machine is full, and continued ſo till you think fit to diſſolve the charm, and ſet the water confined therein at liberty by removing the finger.

Fig. 21, pl. 1, repreſents models of the common houſe and forcing pumps: theſe are ſufficiently deſcribed page 90. Fig. 1 and 2, pl. 5, Mr. Smeaton's pyrometer, fully deſcribed page 229, &c.

Fig. 3, pl. 5, the Rev. Mr. Wm. Jones's pyroſtatical inſtrument, to ſhew the force of expanſion; A, is a bar of braſs or iron placed vertically between the tops of the frame d, d, d, d, and the ſhorter arm of the lever L; the reſt of the inſtrument is a compound ſteelyard; a ſmall weight at Y, counteracting a conſiderable force at X, the motion of the ſhorter arm is rendered very ſenſible by the deal rod. Fig. B, a box to heat the bar A to boiling water. Fig. 5, a circular heater and ſtand for experiments in vacuo. Fig. E, an iron heater. Fig. C, a veſſel for weighing the force of froſt. Fig. D, an occaſional lever when the veſſel is uſed.

Fig. 4, pl. 5, a thermometer.

Fig. 5, pl. 5, an eolipile placed on a ſmall carriage. See page 292.

Fig. 6, pl. 5, repreſents Papin's digeſter. A, B, C, D, the copper veſſel; A B, the cover faſtened down by the ſcrews; at E is the conical valve, which is kept down by the ſteelyard, G, H, and it's moveable weight. See page 290.

Fig. 7, pl. 5, is a ſmall inſtrument for illuſtrating the nature of evaporation and ebullition. See page 314. See page 316 for an account of this inſtrument. Fig. 9, pl. 5, the ſame mounted in a different manner.

Fig. 8, pl. 5, the mode of mounting large burning lenſes. See page 393.

In plate 4, Mr. Lavoiſier's *calorimeter* is repreſented in perſpective at fig. 12. It's interior ſtructure is ſeen fig. 13 and 14, the former being a vertical, the latter an horizontal ſection. f, f, f, f, fig. 13, the interior cavity, into which the ſubſtances are put. b, b, b, b, fig. 13 and 14, the middle cavity to contain the ice which is to be melted; this is ſupported by the grate m, m, under which is placed the ſieve n, n. Theſe two are ſeen ſeparately at fig. 15 and 16. In proportion as the ice is melted,

 the

the water runs into the conical funnel c, c, d, fig. 13; this water may be retained or let out at pleasure by the stop-cock u, y. The external cavity a, a, a, a, fig. 14 and 15, is filled with ice to prevent any effect from external heat on the ice in the cavity b, b, b, b. Fig. 17, the lid to cover the machine. The substances to be operated on are placed in the thin iron bucket, fig. 18, the cover of which has an opening fitted with a cork, into which a small thermometer is fixed. When acids are used, they are put into a glass vessel, as fig. 19, which has also a thermometer fitted to it's neck. Fig. 21 is the interior cavity. Fig. 22, the lid to ditto. See page 253.

APPARATUS FOR ELASTIC FLUIDS.

The tub or trough, fig. 1, pl. 6, is sufficient for every operation that can be performed with water; at the end A B of the tub is a shelf. The receivers, jars, &c. are to be filled first with water in the deep part; and then being turned with their mouths downwards, are to be placed upon the shelf. The water in the tub is always to be about half an inch or more above the shelf. *a* is a small phial, into the neck of which is fitted a bent tube; the end of the tube that fits the bottle is ground so as to be a complete stopple; the elastic fluid generated by any process in the phial, passes through the tube, and rising up into the jar, drives out the water; by this means you fill a jar with such a quantity of air as will be convenient for your experiments.

Fig. 3, pl. 6, represents a marble trough for operating with mercury. Fig. 4, is a section of the trough, with a receiver standing in it's place. f, f, f, measures which have a known proportion to each other; g, g, g, are graduated tubes for eudiometrical experiments.

"Dr. Priestley says, the most accurate manner of procuring air from many substances by heat, is to put them, if they will bear it, into such phials as *a*, *a*, *a*, full of quicksilver, with their mouths immersed in the same fluid, and then throw the focus of a burning mirror upon them: for this purpose, the bottoms should be thin, that they may not be liable to break on a sudden application of heat.

Fig. *b*, pl. 6, a common glass phial, with a ground stopple having many holes in it. This is useful for conveying any fluid or air contained in it through water into a jar, standing with it's mouth inverted in it, without admitting any mixture of common air.

Fig. 2, a phial sufficient for any purpose that does not require more heat than the flame of a candle. If it is to be put into a crucible placed on the fire, the tube in which the ground stopple terminates must be longer, as at e. A long phial, useful for many purposes, is seen at d.

Fig.

Fig. 6, plate 6, a uſeful apparatus for making a quantity of air paſs through a body of water, or any kind of fluid; the air enters by the tube which goes to the bottom of the veſſel, and is delivered by that which is only inſerted at top. Dr. Prieſtley ſays, he has frequently had occaſion to uſe a number of theſe veſſels at the ſame time, that the ſame air may paſs through them all in ſucceſſion. See fig. 7, plate 6.

Fig. 8, plate 6, is Mr. Woulfe's apparatus for diſtilling nitre, conſiſting of a retort *a*, an adopter *b*, a receiver *c* with two orifices, one *d* for the diſcharge of the diſtilled acid, the other *e* as an outlet for the ſuperabundant vapour.

Fig. 9, plate 6, a tin veſſel, incloſing another of iron wire; the outer veſſel is for a charcoal fire, ſurrounding the inner one, which being open at bottom will admit the upper part of a glaſs jar, which may be heated equally as much as the glaſs will bear, without giving more heat than is neceſſary to the lower.

Fig. 10, plate 6, a convenient wooden frame to ſupport ſeveral glaſs tubes in a baſon of water or quickſilver.

Fig. 5, plate 6, the apparatus for impregnating water, deſcribed page 481.

Fig. 11, plate 6, an apparatus for inveſtigating the force of ſteam; it is deſcribed in the next volume. In the original arrangement of theſe Lectures, I deſigned that thoſe on water ſhould have made part of this volume; but from the augmentation they occaſionally received, I found it neceſſary to alter this part of my plan.

Fig. 12, plate 6, repreſents an apparatus for determining the abſolute gravity of the different gaſſes.

Fig. 12, plate 6, is a large balloon, capable of holding 17 or 18 pints, or about half a cubical foot, having the braſs cap b c d e ſtrongly cemented to it's neck, and to which the tube and ſtop-cock f g is fixed by a tight ſcrew. This apparatus is connected by a double ſcrew to the jar B C D, which muſt be ſome pints larger in dimenſions than the balloon. This jar is open at top, and is furniſhed with the braſs cap h i, and ſtop-cock l m.

I determine the exact capacity of the balloon by filling it with water, and weighing it both full and empty. When emptied of water, dry it with a cloth introduced through it's neck d e; the laſt remains of moiſture are to be removed by exhauſting it once or twice by an air-pump.

When the weight of any gas is to be aſcertained, this apparatus is to be uſed as follows: fix the balloon A to the plate of an air-pump by means of the ſcrew of the ſtop-cock f g, which is left open; the balloon is to be exhauſted as completely as poſſible, obſerving carefully the degree of exhauſtion by means of the barometer attached to the air-pump. When the vacuum is formed, the ſtop-cock f g is ſhut, and the weight of the balloon determined with the moſt ſcrupulous exactitude. It is

then

then fixed to the jar B C D, which we ſuppoſe placed in water in the ſhelf of the pneumato-chemical apparatus; the jar is to be filled with the gas you mean to weigh, and then by opening the ſtop-cocks f g, and l m, the gas aſcends into the balloon, whilſt the water of the ciſtern riſes at the ſame time into the jar. To avoid very troubleſome corrections, it is neceſſary, during this firſt part of the operation, to ſink the jar in the ciſtern till the ſurfaces of the water within the jar and without exactly correſpond. The ſtop-cocks are again ſhut, and the balloon being unſcrewed from it's connection with the jar, is to be carefully weighed; the difference between this weight and that of the exhauſted balloon, is the preciſe weight of the air, or gas, contained in the balloon. Multiply this weight by 1728, the number of cubical inches in a cubical foot, and divide the product by the number of cubical inches contained in the balloon; the quotient is the weight of a cubical foot of the gas, or air, ſubmitted to experiment.

An exact account muſt be kept of the barometrical height and temperature of the thermometer during the experiment; a cubical foot is eaſily corrected to the ſtandard. The ſmall portion of air remaining in the balloon, after forming the vacuum, muſt likewiſe be attended to, which is eaſily determined by the barometer attached to the air-pump. If that barometer, for inſtance, remains at the hundredth part of the height it ſtood at before the vacuum was formed, we conclude that one hundredth part of the air, originally contained, remained in the balloon, and conſequently that only $\frac{99}{100}$ of gas was introduced from the jar into the balloon.